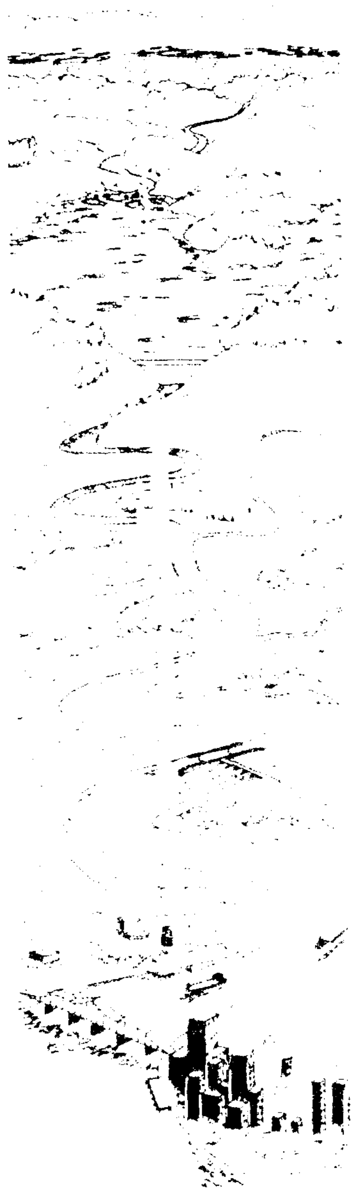
AD-A240 293

US Army Corps of Engineers



WATER OPERATIONS TECHNICAL SUPPORT PROGRAM

MISCELLANEOUS PAPER W-91-2

TECHNIQUES FOR EVALUATING AQUATIC HABITATS IN RIVERS, STREAMS, AND RESERVOIRS

PROCEEDINGS OF A WORKSHOP

Compiled by

Larry G. Sanders

Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

August 1991

Final Report

Approved For Public Release; Distribution Unlimited

91-10448

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

ENVIRONMENTAL LABORATORY

91 9 12 061

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
August 1991

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Techniques for Evaluating Aquatic Habitats in Rivers, Streams, and Reservoirs; Proceedings of a Workshop

5. FUNDING NUMBERS

6. AUTHOR(S)
Larry G. Sanders, Compiler

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Engineer Waterways Experiment Station,
Environmental Laboratory, 3909 Halls Ferry Road,
Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Miscellaneous Paper W-91-2

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers, Washington, DC 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The workshop Techniques for Evaluating Aquatic Habitats in Rivers, Streams, and Reservoirs was held at the US Army Engineer Waterways Experiment Station (WES) on 8-10 August 1989. Purposes of the workshop were to introduce and discuss various techniques used to collect biological and physical information from lentic and lotic environments, with special attention focused on large river systems.

The papers included in this report were submitted by the authors who gave presentations at the workshop, and represent a wide range of topics. Included are papers that address various physical characteristics of river systems, techniques for evaluating aquatic habitats with regard to the fish and invertebrate communities, statistical design for water quality studies, field and laboratory techniques used in benthic and fisheries studies, and the results of intensive fish and invertebrate research.

14. SUBJECT TERMS

Acoustics	Fisheries techniques	Statistical design
Aquatic Habitat	Invertebrates	Water quality
Fish	Larval fish	

15. NUMBER OF PAGES
130

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
UNCLASSIFIED

18. SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT

PREFACE

A workshop was held at the US Army Engineer Waterways Experiment Station (WES) on 8-10 August 1989 to investigate techniques for evaluating aquatic habitats in rivers, streams, and reservoirs. The workshop was conducted by personnel of the Aquatic Habitat Group (AHG), Environmental Resources Division (ERD), WES.

Workshop participants included planners and biologists from the US Army Engineer (USAE) Districts, Sacramento, Los Angeles, Buffalo, Seattle, St. Paul, Louisville, and Omaha, and the USAE Divisions, North Pacific and Pacific Ocean. This report includes papers presented by the attendees and summarizes the topics discussed.

The work reported herein was conducted as part of the Water Operations Technical Support (WOTS) Program. The WOTS Program is sponsored by the Headquarters, US Army Corps of Engineers (HQUSACE), and is assigned to the US Army Engineer Waterways Experiment Station (WES) under the purview of the Environmental Laboratory (EL). Funding was provided under Department of the Army Appropriation No. 96X3123, Operations and Maintenance. WOTS is managed under the Environmental Resources Research and Assistance Programs (ERRAP), Mr. J. L. Decell, Manager. Mr. A. J. Anderson was Assistant Manager, ERRAP, for WOTS. Technical Monitors during this study were Messrs. David Buelow and James Gottesman, HQUSACE.

The work was conducted under the general supervision of Mr. Edwin A. Theriot, Chief, AHG; Dr. Conrad J. Kirby, Chief, ERD; and Dr. John Harrison, Chief, Environmental Laboratory.

COL Larry B. Fulton, EN, was Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

This report should be cited as follows:

Sanders, Larry G. 1991. "Techniques for Evaluating Aquatic Habitats in Rivers, Streams, and Reservoirs; Proceedings of a Workshop," Miscellaneous Paper W-91-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

CONTENTS

AGENDA

WATER OPERATIONS TECHNICAL SUPPORT PROGRAM - WORKSHOP

Techniques for Evaluating Aquatic Habitats in Rivers, Streams, and Reservoirs

US Army Engineer Waterways Experiment Station
8-10 August 1989

Tuesday, 8 August 1989

7:45 a.m.	Registration	Mr. Larry Sanders, CEWES
8:30 a.m.	Welcome	Dr. John Keeley, Assistant Chief, Environmental Laboratory, CEWES
8:45 a.m.	WOTS Program	Mr. Lewis Decell, Program Manager, Environmental Resources Research and Assistance Programs, CEWES
9:00 a.m.	Orientation and Workshop Objectives	Mr. Edwin A. Theriot, Chief, Aquatic Habitat Group, CEWES
9:30 a.m.	BREAK	

Session I: Characteristics of Aquatic Habitats

9:45 a.m.	Physical	Mr. Tim Ethridge, CELMV
10:30 a.m.	Biological	Dr. Carl Way, CEWES
11:15 a.m.	Habitat Classification	Mr. John Baker, CEWES
12 noon	LUNCH	

Session II: Techniques for Evaluating Aquatic Habitats

1:00 p.m.	Water Quality	Dr. Robert Gaugush, CEWES
1:45 p.m.	Freshwater Mussels	Dr. Andrew Miller, CEWES
2:30 p.m.	Aquatic Insects and Other Macroinvertebrates	Dr. David Beckett, University of Southern Mississippi
3:15 p.m.	Demonstration: Field and Laboratory Techniques	Staff

Wednesday, 9 August 1989

8:00 a.m.	Larval Fishes	Dr. William Pearson, University of Louisville
9:15 a.m.	Adult Fishes	Mr. Jack Killgore, CEWES
10:00 a.m.	Hydroacoustics to Assess Fish Populations	Mr. Richard Kasaul, CEWES
10:45 a.m.	Orientation for Field Trip	Mr. Larry Sanders, CEWES
11 a.m.-5 p.m.	FIELD TRIP	

Thursday, 10 August 1989

Session III: Data Analysis and Interpretation

8:00 a.m.	Aquatic Zones in Alluvial Rivers and GIS Applications	Mr. Stephen Cobb, CELMV
8:45 a.m.	Laboratory and Field Experiments to Evaluate Environmental Impacts	Dr. Barry Payne, CEWES
9:30 a.m.	BREAK	

Session IV: Application of Techniques

9:45 a.m.	Fishery Investigations	Dr. Jim Gammon, DePauw University
10:30 a.m.	Invertebrate Studies--Methods for Using *Hexagenia* Mayflies (Ephemeroptera: Ephemeridae) as Biological Monitors of Water Quality in the Upper Mississippi River	Dr. Calvin Fremling Winona State University
11:15 a.m.	Panel Discussion	Staff
12 noon	ADJOURN	

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
feet	0.3048	meters
horsepower (550 foot-pounds (force) per second)	745.6999	watts
inches	2.54	centimeters
miles (US statute)	1.609347	kilometers
yards	0.9144	meters

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F = 32) + 273.15$.

TECHNIQUES FOR EVALUATING AQUATIC HABITATS IN RIVERS, STREAMS, AND RESERVOIRS

PROCEEDINGS OF A WORKSHOP

INTRODUCTION

The determination of biological and physical characteristic of rivers, streams, and reservoirs is often difficult. This is particularly true in large rivers where fish and other organisms are highly mobile and species composition in a given reach may change with season of the year and river stage. During the Environmental and Water Quality Operational Studies (EWQOS) Program, considerable effort was made to evaluate various sampling methods to determine the most effective techniques for various types of aquatic environments. Since those studies were completed, techniques have been refined and improved to provide more reliable data and to reduce sampling effort.

Purposes of this workshop were to introduce and discuss various techniques used to collect biological and physical information from lentic and lotic environments, with special attention focused on methods developed for large rivers. This was accomplished through lectures, discussions, equipment displays, periods for hands-on familiarization, and laboratory activities.

CHARACTERISTICS OF AQUATIC HABITATS

PHYSICAL CHARACTERISTICS OF STREAMS

Tim Ethridge*

Introduction

Rivers and streams are dynamic systems that are constantly changing in response to physical conditions. The amount of water that a system receives (rainfall) and the type of material that it flows through (geology) are the two main factors that influence the shape and behavior of streams. Other factors such as vegetation, topography, and groundwater not only affect stream behavior but also interact with each other. For example, climate and geology have an effect on vegetation and topography. Vegetation, which affects the flow of water, affects erosion, which then shapes the topography. Changes in topography, on the other hand, influence growth patterns of vegetation. The stream itself has an effect on some of these variables, since it is capable of moving materials, shaping the topography, affecting vegetation growth, and influencing groundwater.

The Drainage Basin

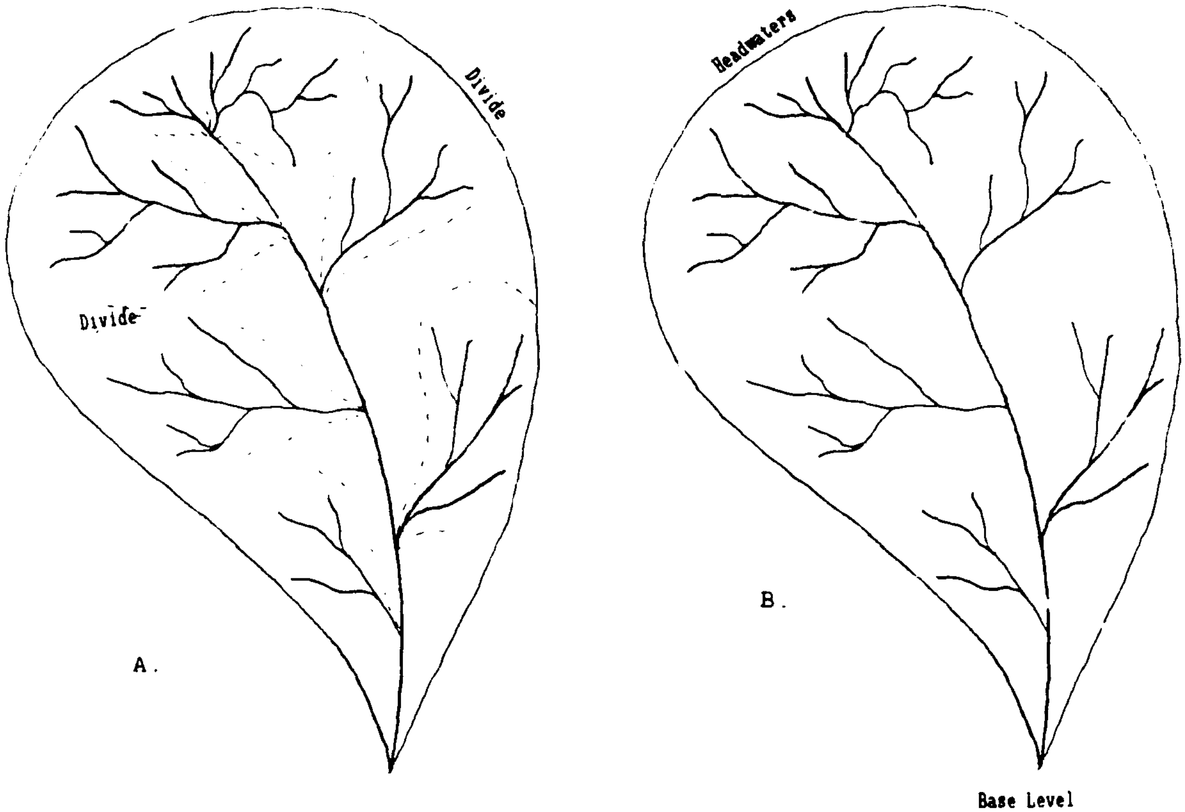
Description

The drainage basin, also called a watershed, is a network of channels through which water flows from high to low ground (Figure 1). A basin may be part of a larger drainage system and may also contain smaller basins within its boundaries (Figure 1a). A complete drainage system may consist, therefore, of a basin within a basin, the largest of which might reach a continental scale. The Mississippi River drainage basin, for example, drains about 40 percent of the continental United States.

The components of a drainage basin can be described in terms of location within the basin. The ridge of high ground around the perimeter of a basin is called the divide, which marks the boundary between the basin and other adjacent basins (Figure 1a). Channels in this part of the basin have very steep slopes. Waters flowing in these steep channels are referred to as headwaters (Figure 1b). The lowest point in the basin, or the lowest point at which a

---

* US Army Engineer Division, Lower Mississippi Valley, Vicksburg, MS.



a. Divide b. Headwaters

Figure 1. Drainage basin

stream channel can erode, is called base level. In general, the mouth of a stream is its base level. Therefore, each channel has its own base level. The base level for a stream and the basin it drains may be a lake, another channel, or the ultimate base level--the ocean.

When rain falls on a drainage basin, part of the water is absorbed into the ground, and part of it flows over the ground as surface runoff. The runoff flows from one channel into another as it passes from the headwaters to base level. As water flows from high to low ground, it passes through three zones within the basin: (a) the sediment production zone, (b) the sediment transport zone, and (c) the sediment deposition zone. The sediment production zone is the zone of steep channels that begins in the headwater areas of the basin. This zone has a large number of channels per unit area and generally erodes the most material within the basin. The middle zone of the basin is the sediment transport zone. Channels in this zone have more gentle slopes and have fewer channels per unit area. The channels generally transport more sediment than they erode. The third zone, or sediment deposition zone, is base level for the basin. Channel slopes in this zone are nearly flat, and the waters can no longer carry the sediments eroded from the basin. If the sediments are not transported into another system, they will be deposited in an alluvial fan or delta.

Drainage patterns

As a basin erodes or develops over an area, its shape forms according to the erodibility of the material through which it is flowing. Patterns that develop over hard rock are different from those that form over more erodible material. The most common pattern, which forms over fairly uniform material is the dentritic pattern, which resembles the pattern of veins in an oak leaf (Figure 2). A rectangular pattern may develop where geologic controls such as jointing or faulting influence the drainage. Drainage that forms over a geologic dome may form a radial pattern, while that over parallel outcrops forms a parallel pattern.

As basins develop, they may expand their boundaries at different rates. One basin may erode through the divide and take over part of the drainage from an adjacent basin. This can occur through a gradual process of erosion or through a more dramatic event known as stream capture. Stream capture occurs when the headwater(s) of one stream erodes through the banks of another and captures that tributary.

Drainage density

Basins develop through a series of stages. The evolution of a drainage basin can be broken down into early, middle, and late stages. A drainage basin could also be described as being either young or mature. As the basin evolves, its drainage density changes. Basins are commonly described in terms of their drainage density, which changes as the basin develops. For example, a basin with a large number of channels may be classified as a high-density basin. A low-density basin is one with few channels per unit area (Figure 3). If a basin is uplifted or its base level lowered through some geological event, the erosional process will start over again, beginning with the early stage of development.

Basin analysis

There are also quantitative methods of analyzing drainage networks. Perhaps the most basic of these is stream order, which is an expression of the degree of branching in a drainage system. Strahler's method is the most common method of counting stream order. Using this method, the smallest unbranched tributaries in the basin are numbered as order one. When two first-order channels come together, they form a second-order channel; two

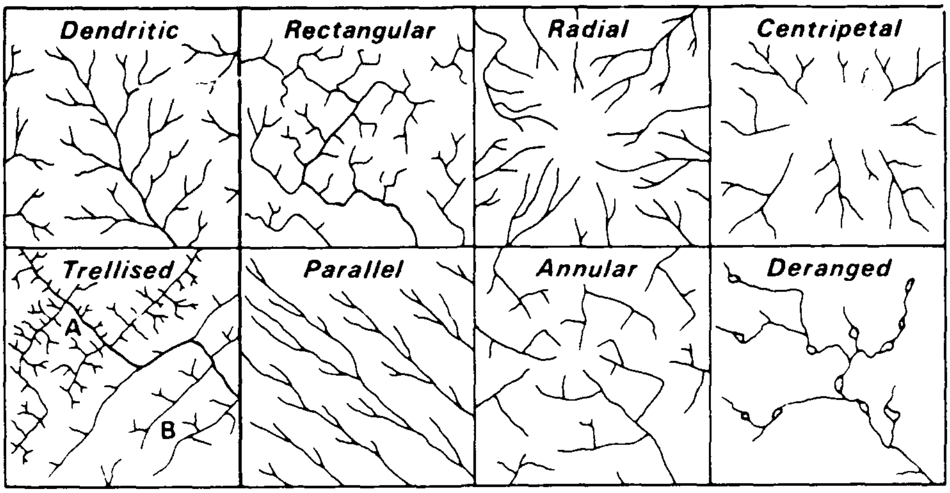


Figure 2. Drainage patterns

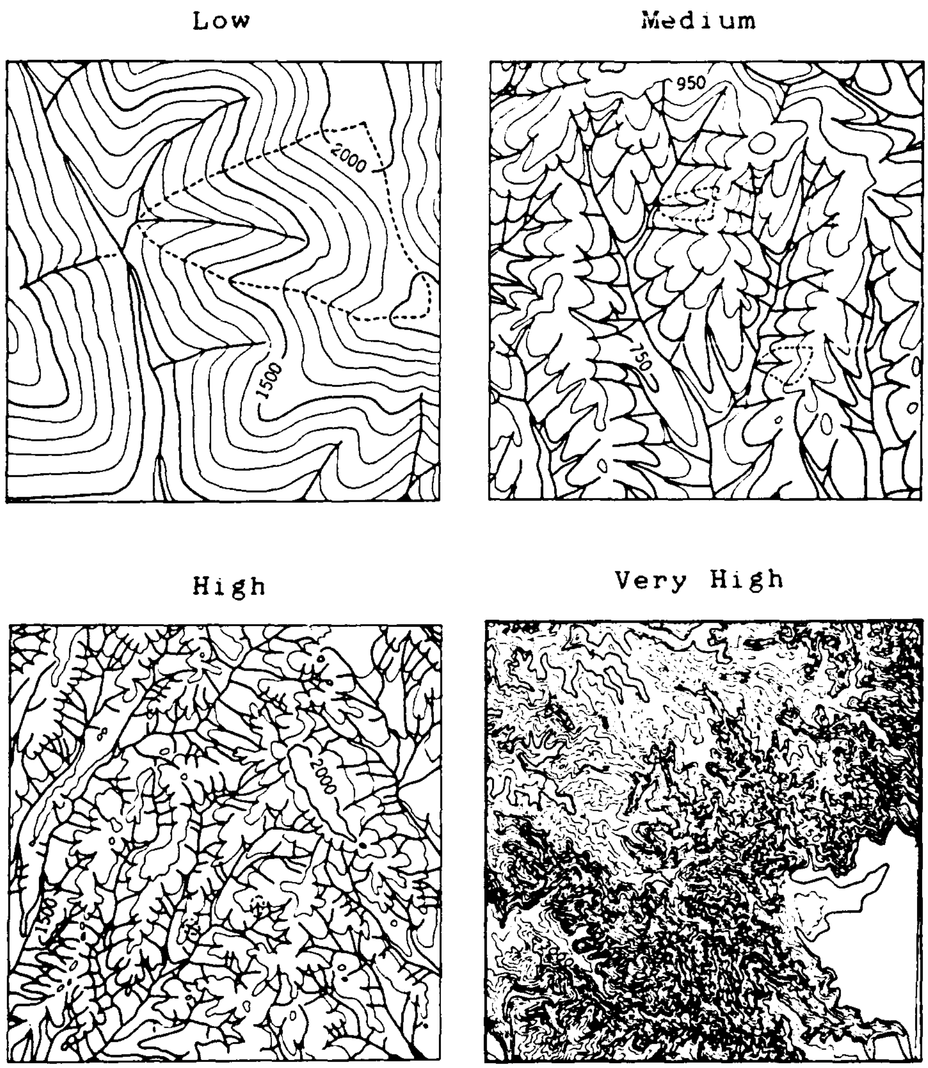


Figure 3. Drainage density

second-order channels form a third-order channel, and so on (Figure 4). The highest order channel in the basin is said to be the order of that basin. For example, a drainage basin that branches to the fifth level is said to be a fifth-order system. When the number of channels of each order is plotted against the order number and a regression line fit to the data, the slope of the line is called the bifurcation ratio. Figure 5 represents a basin with 139 streams of order one, 46 streams of order two, and so on. A plot of the data results in a regression line with a slope of 3.52. This means that there are 3.5 times as many channels of one order and the next higher order. Other quantitative analyses, such as texture ratio and hypsometric integral, are used to describe drainage basins, but a description of these techniques goes beyond the scope of this paper.

Stream order and bifurcation ratio are valuable tools used to describe a drainage basin, particularly when comparing one basin to another. For basins of the same type (i.e., dentritic, trellis, radial, etc.) and shape, the bifurcation ratio, stream order, and other ratios will be the same, regardless of the difference in size between basins. This can be useful when describing basins for which there are no data and no measurements have been taken.

Stream Channels

Types of channels

When a drainage basin receives rainfall, water not only flows over the ground surface and in the channels, but through the ground as well. Under certain conditions, the channel may be flowing above groundwater level, in which case it may contribute to the groundwater table. These streams are called influent streams. At other times, groundwater levels may be above the channel flow, in which case the groundwater may contribute water to the channel. These streams are called effluent streams. Streams that flow above the groundwater table and do not receive a constant water supply from springs, melting snow, or other sources may carry flow only when it rains. A stream or portion of a stream that flows only in direct response to precipitation is called an ephemeral stream. Streams that flow year round and from source to mouth are called perennial streams.

Vegetation

Ground cover, such as vegetation, man-made surfaces, etc., can affect the amount of infiltration and surface runoff. Vegetation reduces the amount

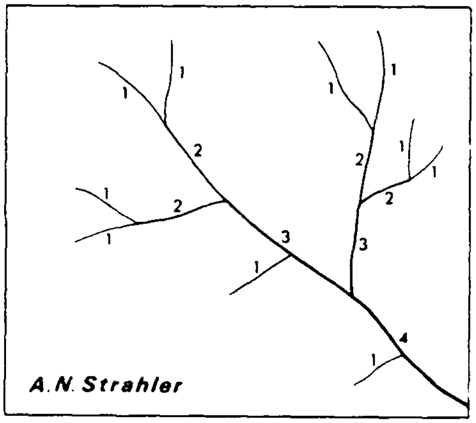


Figure 4. Stream order (based on Strahler method)

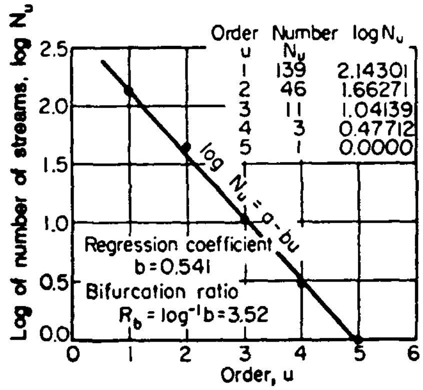


Figure 5. Bifurcation ratio

of surface runoff and thus increases the amount of infiltration. Generally, the higher runoff is associated with higher erosion rates, except for areas covered with man-made surfaces such as concrete or asphalt. As sediments are eroded, they are transported through the channels, deposited, and retransported through the system.

Sediment transport

The amount of sediment a stream can transport varies depending on the size of the material and the velocity of the flow. The Hjulstrom diagram (Figure 6) shows that a threshold exists in which sediment transport can occur. If velocities are too low or particle size too large, deposition occurs. Erosion occurs throughout a zone of high velocity, depending on the size of the material. Lane's equation (Figure 7) illustrates the balance between sediment load and stream discharge and states that

(Sediment load) × (Sediment size)
is proportional to
(Stream slope) × (Stream discharge)

If the channel slope or the amount of water increases, the stream is capable of carrying more material, and degradation (erosion) will occur. If the sediment load or grain size increases, the balance will tip the other way and aggradation (deposition) will occur.

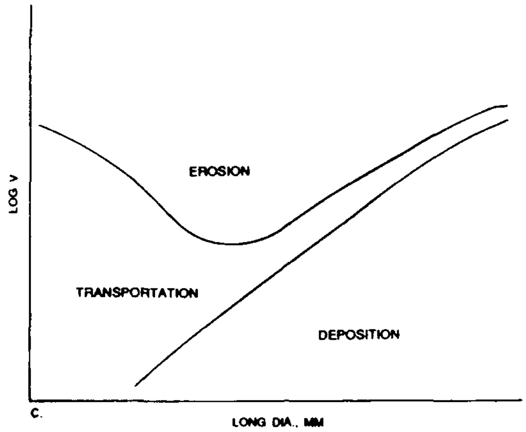


Figure 6. Hjulstrom's diagram

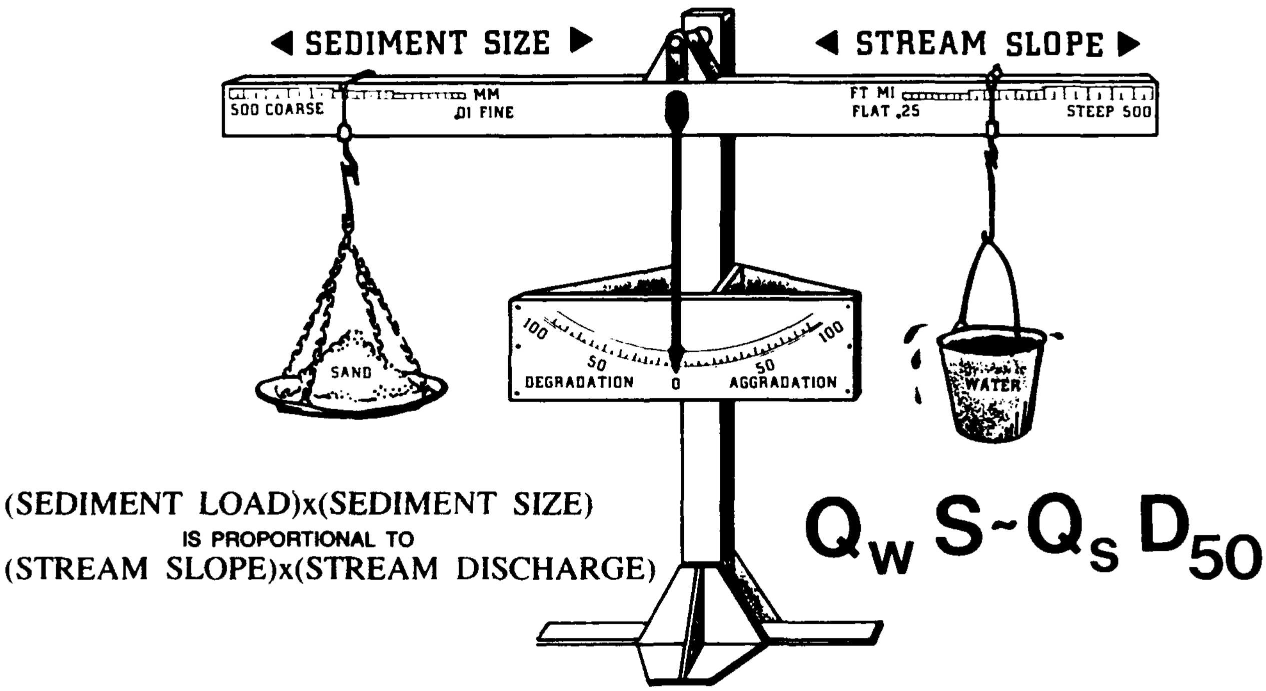


Figure 7. Lane's equation

Stream slope

Once the sediment load exceeds the limit that the stream can carry, the stream will deposit sediments. As the channel scours and deposits material, it changes the slope on which it flows. As the high points are eroded and low points are filled, the system approaches a state of equilibrium. For example, if the slope is not steep enough for a stream to carry its sediment load, it will increase its slope by depositing the excess sediments. Streams that have become fairly stable and carry the sediment load fairly efficiently are called "graded" streams. A graded stream has adjusted its slope, in relation to discharge and other channel characteristics, so that it has the velocities to transport the sediment load supplied from the drainage basin. Although a graded stream is in equilibrium, a change in the controlling factors will cause a displacement of the equilibrium in a direction that will tend to absorb the effect of the change. If the stream system can make the adjustment efficiently, it should return to a graded condition. In this sense, we treat rivers and streams as living entities by saying things like "the stream is trying to adjust its slope," etc.

Channel patterns

The individual stream channel takes on a characteristic shape in response to the amount of water the channel receives, the slope on which it flows, and the material it flows through. The hydraulic force of flowing water erodes material from the channel, transports it, and redeposits it downstream.

Three basic types of channels form as a result of these effects: straight, meandering, and braided. Straight channels seldom exist for any length of time in nature, since flowing water has a natural tendency to meander. In an ideal situation, such as a man-made rectangular flume flow, velocities are nearly uniform with the highest velocities in the center and near the top of the channel (Figure 8). The stream boundaries are resistant to flow; therefore, the slower velocities are along the sides of the channel. An obstruction or hard point in the channel will disrupt the flow by resisting the flow around it (Figure 9a). Once the flow is altered, it rebounds after passing the point of resistance and begins to oscillate back and forth as it moves downstream. The effect dampens out at some point downstream, depending on various flow conditions. As the flow oscillates in the channel, the zone of high velocity shifts from side to side (Figure 9b). The faster flow scours the channel banks, while the slower water deposits sediments (Figure 9c).

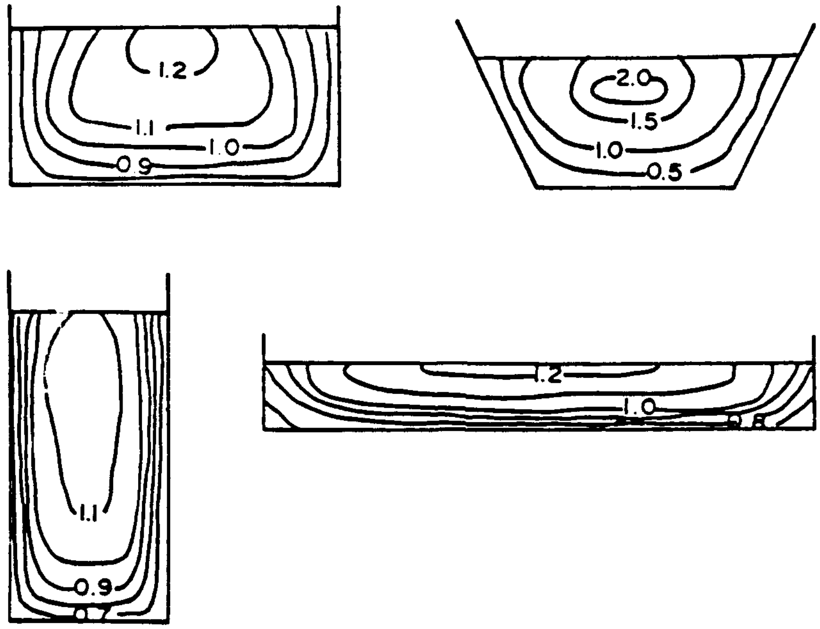


Figure 8. Velocity distribution in channels of different shapes. Contours are lines of equal velocity

Once the meandering process begins it tends to perpetuate itself, and the meandering process continues.

Meandering streams

As water flows around a bend, the zone of high velocity shifts to the outside of the bend, while the lower velocities occur on the inside of the bend. The effect is similar to riding a roller coaster. As you ride through a curve to the right, your weight throws you to the left. In a curve to the left, you will fall to the right. This zone of high velocity is called the "thalweg" of the channel (Figure 9d). Since fast-moving water erodes material, the outside of bendways will scour deep "pools" (Figure 9e). On the inside of bendways, where velocities are slower, sediments that can no longer be carried by the flow will fall out and be deposited in the channel. The bars that develop on the inside of the bendways are called point bars. As point bars develop, the larger sediments drop out first while the finer sediments are deposited last. Sediments in point bar deposits, therefore, increase in grain size from top to bottom. As the flow leaves a bendway and approaches another, it passes through a relatively straight reach in which flow and deposition become more centralized. Deposition occurs roughly in the center of the channel, while the deeper portions occur on each side of the channel. These areas of central bar development are called "crossings."

Crossings are actually the connection between one point bar and the next downstream point bar (Figure 9f).

Sinuosity

As a stream meanders, it is constantly eroding and depositing material in an effort to adjust its slope. The meandering process increases the stream length with respect to valley length. The ratio of stream length to valley length is called sinuosity. If the straight-line distance between two points is 1 mile* but the actual curved length of the stream is 3 miles, the sinuosity is 3 (Figure 10). Sinuosity is one way of describing the physical characteristics of a stream. The sinuosity of a channel can also be described in terms of wavelength and amplitude of the sinuous pattern.

The meandering process may increase to a point and the wavelength become so short that a meander bend will eventually cut itself off. This can occur by two adjacent pools scouring into each other or by a cutoff process in which flow cuts across a point bar during high flow. When the latter occurs, the cutoff channel is called a back-chute. The abandoned bendway, which becomes cutoff from the main channel flow, is called an oxbow lake. Note that shortening the channel length changes the slope of the channel. For example, if the slope through a bend originally dropped 6 in. in 1,000 ft but is suddenly cut off to 500 ft, the 6-in. drop occurs over a shorter distance. Therefore, the local slope is increased, which increases velocities through the reach. The increased velocity will scour the channel is an attempt to readjust the slope. Beyond the bendway, where slopes and velocities are reduced to normal, sediments from the scoured area will be deposited, which further balances the channel slope.

Braided streams

A braided stream is made up of several meandering channels, the combinations of which may occur in a variety of patterns. A channel may change from one type to another from one bendway to the next. These combination channels may be described in a variety of terms, such as a sinuous braided channel or a braided straight channel. Therefore, all natural channels tend to meander to some extent. A braided channel consists of several meandering channels, and even a straight channel exhibits some meandering characteristics.

---

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 6.

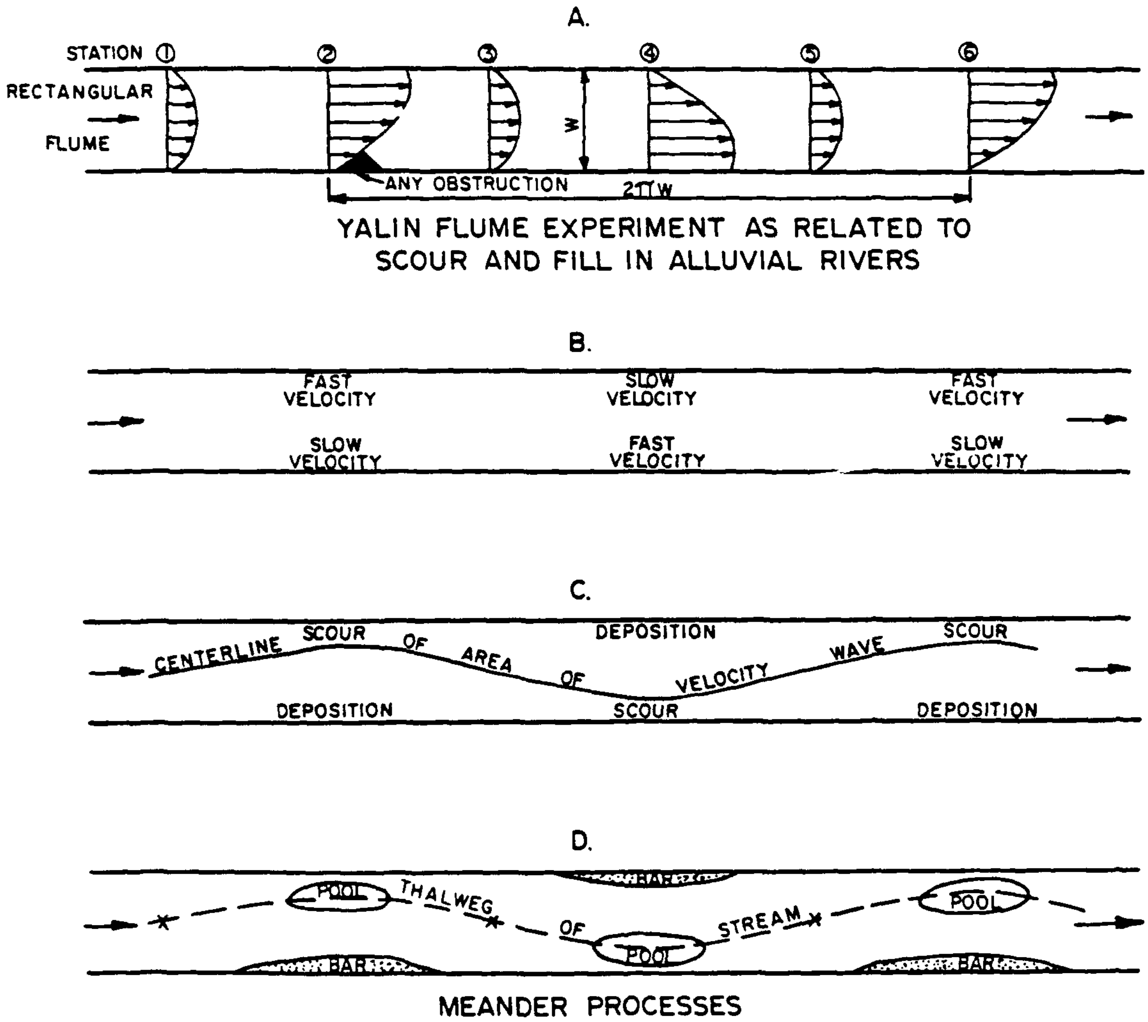


Figure 9. Stream meandering process (Continued)

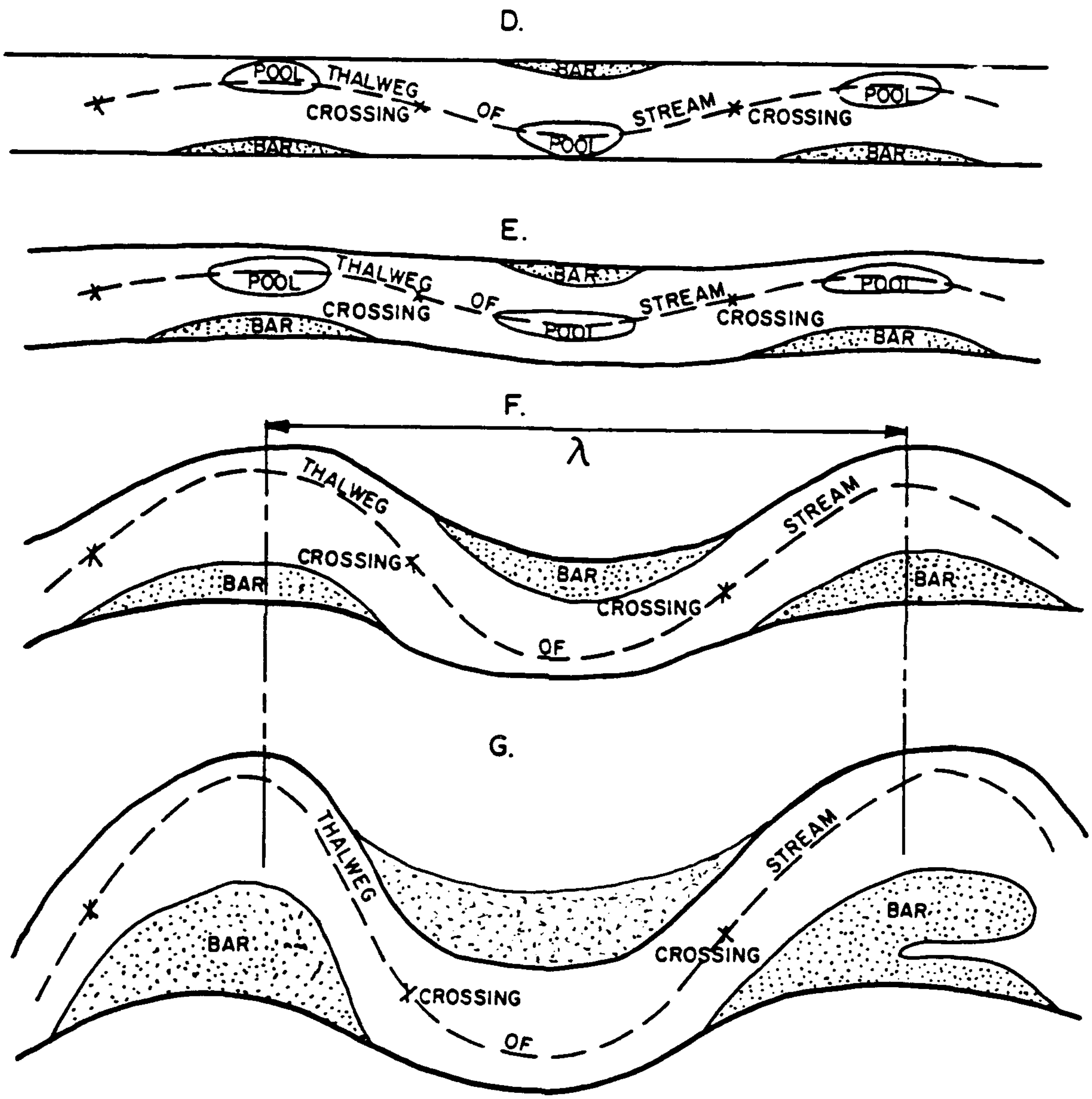


Figure 9. (Concluded)

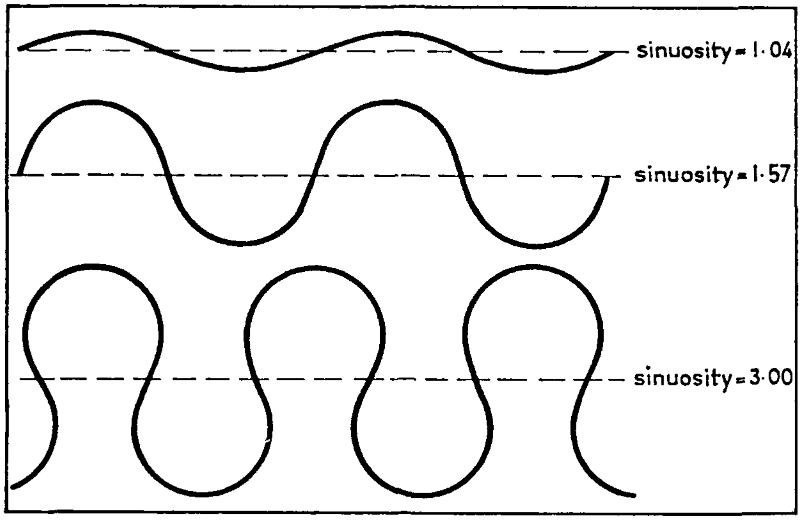


Figure 10. Sinuosity

Flow characteristics

During high flows, the zone of high velocity tends to straighten out in the channel. During floods, when waters flow out of banks, the zone of high velocity runs more or less in the center of the channel and actually cuts straight across the pools and point bars. If the flooded condition exists long enough, a new, larger meander pattern will eventually develop. Note that the same processes are going on, but at a different scale. The opposite effect can be seen when the water level or stage drops in the channel. The straight reach between two meander bends may contain a much smaller stream that meanders or becomes braided and develops its own pools and point bars on a much smaller scale. Again, the same processes are occurring in each case, but with a different magnitude.

Sediment Transport

Sediment movement changes as flow conditions change in the channel. A low-flow channel, for example, may have to convey sediments that were deposited by the previous high-flow channel. During low flow, sediment is scoured from the steeper sloped crossings and from the banks where the flow impinges. Sediments are deposited in the flatter sloped pools where velocities are slower (Figure 11). As the water level rises to midbank level, slopes tend to be uniform over pools and crossings. Scour and deposition of channel sediments are controlled by local geometry (Figure 12). During high flows, the

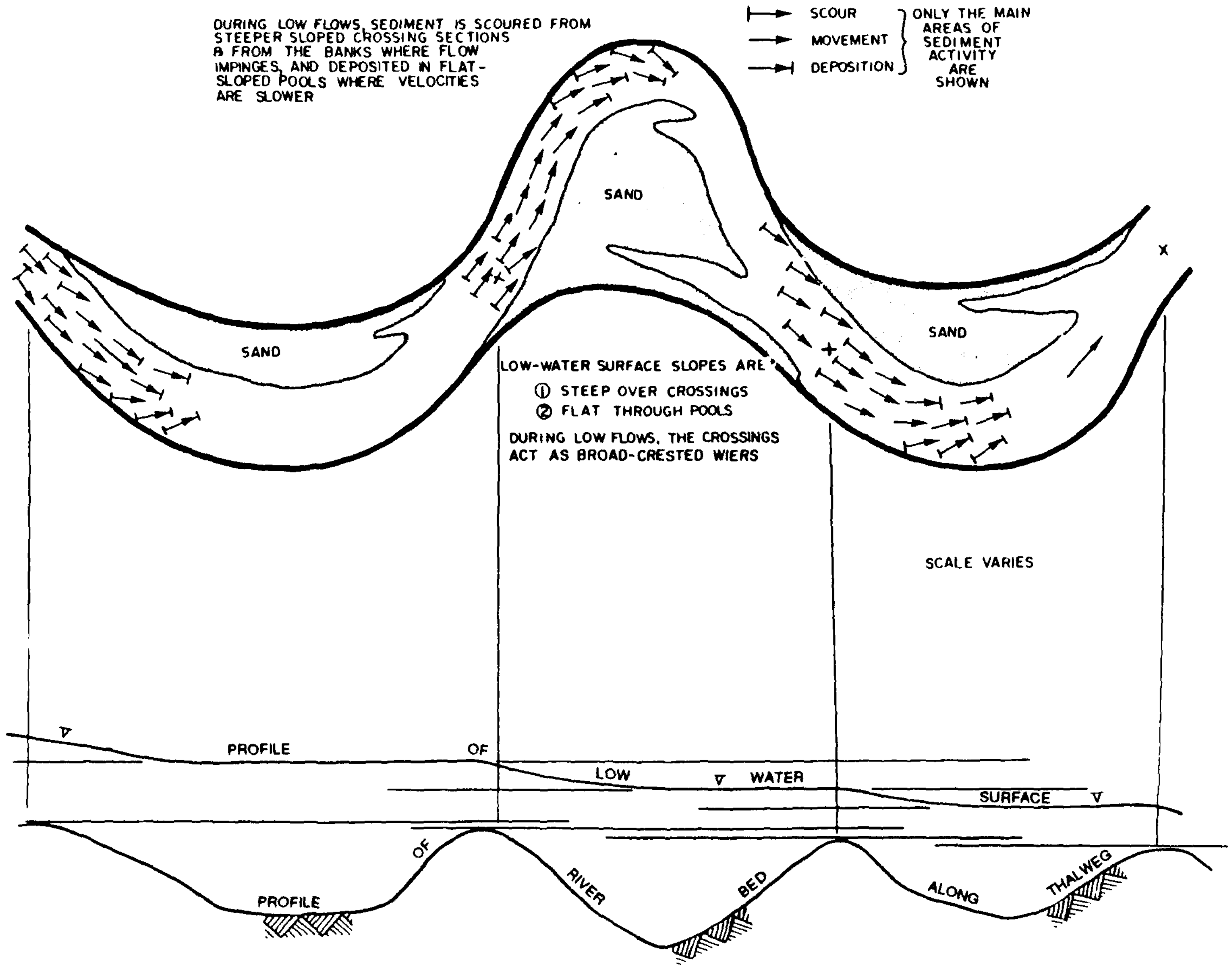


Figure 11. Low water sediment movement

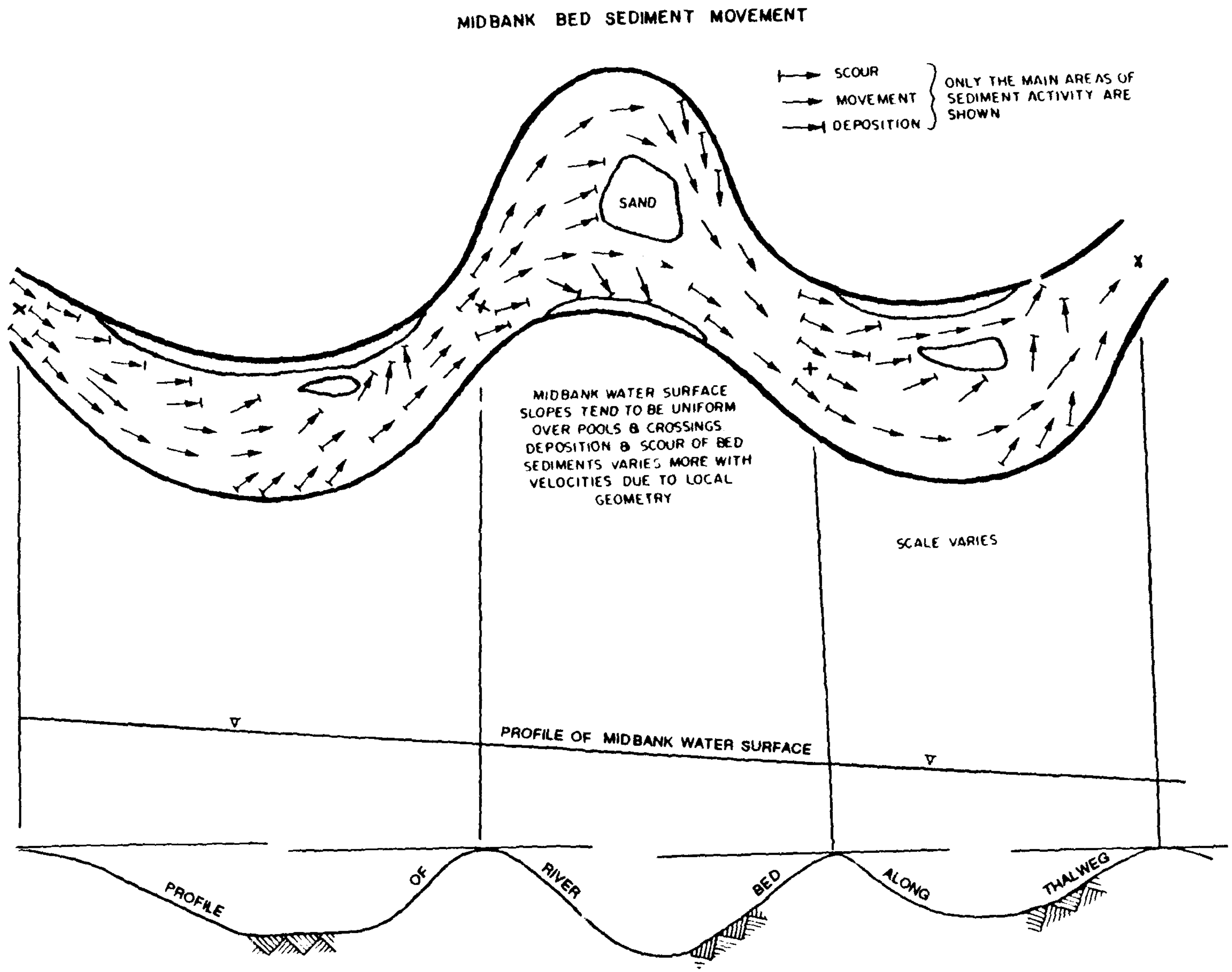


Figure 12. Midbank sediment movement

crossings fill with sediments and the point bars act like weirs or control points in the channel (Figure 13). Eventually during high flows, the bars and crossings will become filled with sediments. As stages drop, the crossings are scoured out as the stream redirects the flow. The main path of sediment movement through the entire hydrography (low, to high, to low flow) is a meandering bar, the movement of which falls within the confines of the main channel (Figure 14). As the stream meanders, the sediment movement meanders also, but with different sinuosity.

The Deposition Zone

Eventually the sediments transported through a drainage system will reach base level for the system. At this point, flow might join another system as a tributary to a larger channel or may enter a lake or ocean. Under certain conditions, flow empties on dry land. Sediments deposited at base level form a fan-shaped bar or delta. As the flow enters the deposition zone, sediments fall out in the same sequence as point bar deposition. The largest sediments are deposited first, and the finer sediments last. The finer sediments stay in suspension longer and are deposited farther out in the delta.

Summary

Two important points must be noted in the discussion of the physical characteristics of rivers and streams: (a) water follows the path of least resistance and is constantly seeking to obtain a state of equilibrium and (b) the same processes that take place in the channel and the basin are occurring at different magnitudes. Notice the geometric similarity between drainage basins of different sizes and the occurrence of smaller basins within basins. The same effect occurs in the stream channel as one channel may contain smaller streams at low flow and a larger stream during floods. Both the drainage basin and the stream channel are trying to reach a state of equilibrium.

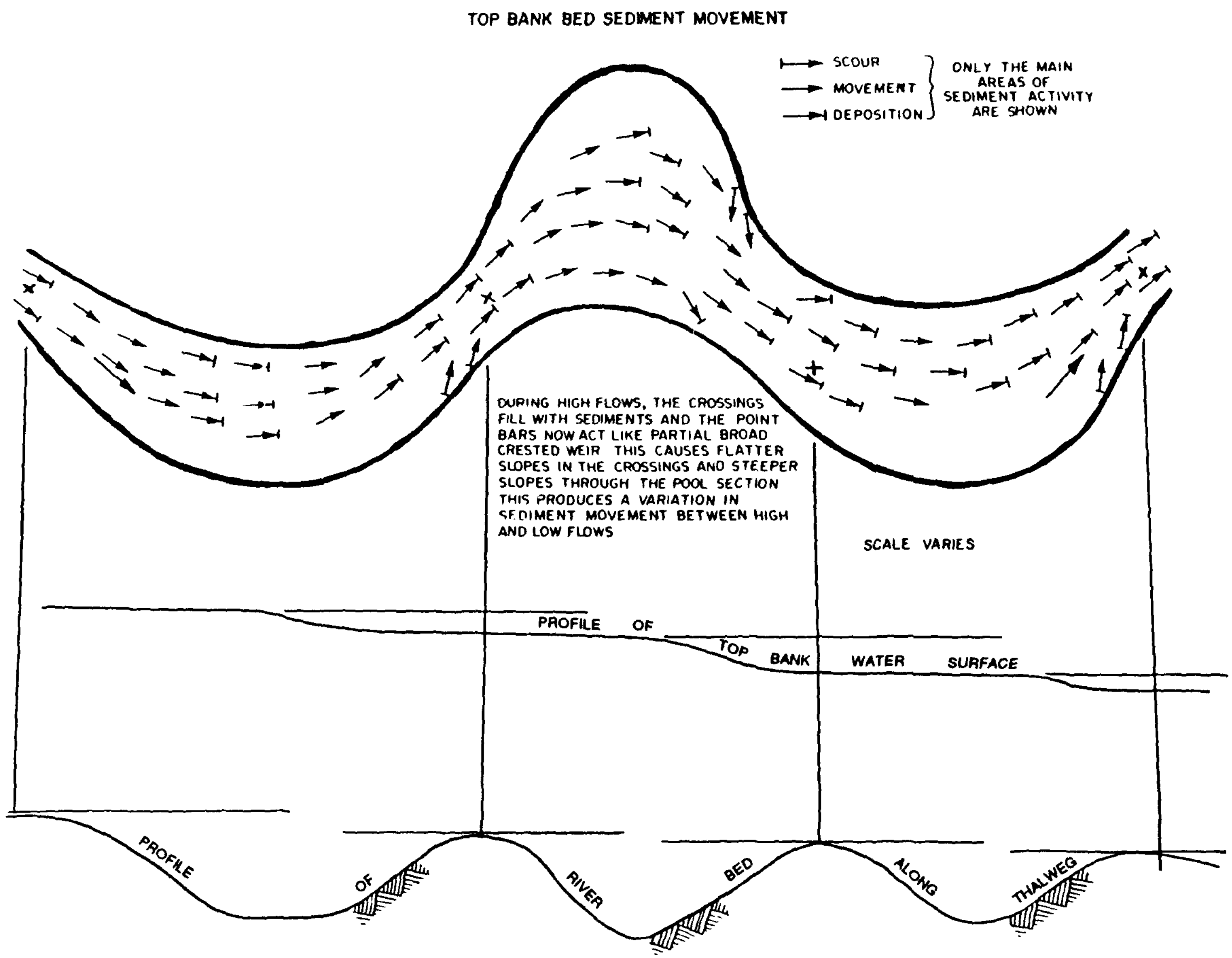


Figure 13. Top bank sediment movement

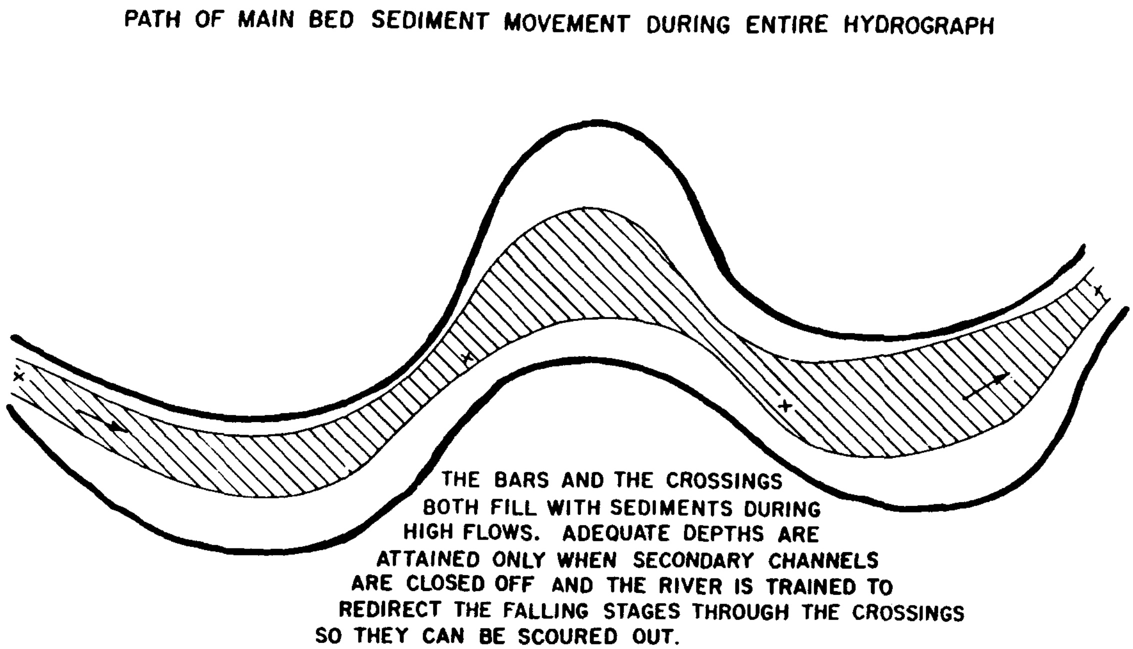


Figure 14. Path of main bed sediment movement

STRUCTURE AND FUNCTION OF STREAM ECOSYSTEMS

Carl M. Way*

Rivers vary considerably in their size and surrounding watershed and in the relative importance of physical and biological processes to the overall ecology of the system. The classification of streams is based upon viewing a stream as a subset of the surrounding watershed and proceeds in a hierarchical manner. A first attempt at stream classification would be to determine stream order. The Strahler system is commonly used and defines a first-order stream as the first permanently flowing channel; a second-order stream is when two first-order streams join; a third-order stream is when two second-order streams join; etc. Once the particular order of a stream has been identified, specific physical properties which describe a reach of stream can be measured including discharge (Q), reach area (km^2), width (m), depth (m), and slope (percent change in gradient). The traditional riverine habitat classification system divides streams into erosional versus depositional, pool versus depositional, or pool versus riffle habitats. This scheme is not adequate for large rivers like the Mississippi River. For large rivers it becomes necessary to use habitat categories derived from lentic systems. These include limnetic, littoral, and profundal habitats, categories that are much more descriptive of habitat features found in large rivers.

One approach to studying the structure and function of stream ecosystems is from a biological perspective. Vannote et al. (1980) developed a theory that emphasizes the origins and fates of organic resources and inorganic nutrients. Vannote et al. viewed a stream as a subsystem of its watershed or drainage basin. Stream order, channel geomorphology, annual hydrologic pattern, and the riparian vegetation determine the type and functioning of biological communities. These ideas arose from studies in the 1970s of detritus dynamics in headwater streams which demonstrated the importance of organic inputs from riparian zones in influencing the biological community. The riparian zone largely determines the balance between animal and plant communities through light alteration and supplies of allochthonous materials. Stream ecologists use a ratio to loosely quantify this balance between animal and plant communities, known as the P/R ratio. This is a relationship between

* US Army Engineer Waterways Experiment Station, Vicksburg, MS.

rate of gross primary production (P) and community respiration (R) or a ratio of autotrophy to heterotrophy. If $P/R > 1$, the community is said to be autotrophic; if $P/R < 1$, the community is heterotrophic. For example, in headwaters, primary production is controlled by available light. These streams generally have closed canopies and a $P/R < 1$, and are heterotrophic. This information has been used by Vannote et al. (1980) to provide a general conceptual framework for studying stream ecology, known as the River Continuum concept. Heterotrophic communities are characteristic of first-, second- and third-order streams with annual P/R ratios <1. Wider rivers (orders 4-6) are characterized by having most of their organic input originating from upstream sources as compared with riparian zones. These midsized rivers have an annual P/R ratio greater than 1. Very large rivers, orders 7 and greater, tend to be heterotrophic. This is primarily a feature of reduced light penetration with increased depth due to turbidity.

The River Continuum concept views a stream as a continuous drainage system from headwaters to river mouth. The basic element of the hypothesis is the dependence of downstream biological communities on upstream processes--communities in each successive stream order are dependent upon the inefficiency or "leakage" from the preceding orders. The theory emphasizes the importance of terrestrial inputs of coarse particulate organic matter (CPOM) and the transport of fine particular organic matter (FPOM). The storage-cycle-release nature of open flowing-water ecosystems is embodied in the concept of nutrient spiraling (Minshall et al. 1983), which describes how nutrients are transported in the River Continuum.

The process-oriented interest in the sources and fates of organic substrates in streams proposed by the River Continuum has led to the classification of organisms on the basis of biological function. In particular, stream macroinvertebrates are categorized on the basis of morphological-behavioral adaptations for food acquisition (Cummins 1974, Cummins and Klug 1979). Most macroinvertebrates are omnivores, but their mechanisms for obtaining food are more restrictive. The major functional groups of macroinvertebrates in streams are shredders (feeders on CPOM such as leaf litter), scrapers (raspers of periphyton from hard substrates), piercers (suck cellular fluids from macrophytes), collector/gatherers (feed primarily on FPOM), and predators. The functional group approach can be used to compare biotic communities across a variety of aquatic habitat types.

Summary

What are the biological concerns characteristic of large rivers such as the Mississippi River? Little is known about the biological communities found in large rivers (>7th order). Most research and theories (such as the River Continuum) come from work on smaller order systems. This is because stream ecologists traditionally studied smaller order streams to avoid the logistics involved in conducting even moderate sampling in large-order rivers. The combination of current velocity, depth, and water levels makes sampling extremely expensive, difficult, and often hazardous. However, there are numerous questions to be answered with respect to large riverine ecology that are of interest to the Corps. Does the River Continuum concept hold for large-order rivers like the Mississippi River? How important are snags in large rivers, and how has man's activities affected the biotic processes in large rivers (e.g. channelization, clearing and snagging, dredging, barge traffic)?

References

Cummins, K. W. 1974. "Structure and Function of Stream Ecosystems," Bioscience 24:631-641.

Cummins, K. W., and Klug, M. J. 1979. "Feeding Ecology of Stream Invertebrates," Annual Review of Ecology and Systematics 10:147-172.

Minshall, G. W., Petersen, R. C, Cummins, K. W., Bott, T. L., Sedell, J. R., Cushing, C. E., and Vannote, R. L. 1983. "Interbiome Comparison of Stream Ecosystem Dynamics," Ecological Monographs 53:1-25.

Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R., and Cushing, C. E. 1980. "The River Continuum Concept," Canadian Journal of Fisheries and Aquatic Science 37:130-137.

AQUATIC HABITATS IN LARGE RIVER SYSTEMS

John A. Baker*

It is well established that different fish species often use different subsets of the physical environment (Ross 1986). One fish, for example, may inhabit only riffles within streams, while another fish lives only in pools. Modification of aquatic systems, whether by chance or by design, usually changes the amount, variety, and relative abundances of these habitats, and as a consequence changes the kinds and abundances of organisms living there. Thus, by designing projects to minimize alteration of habitats, particularly ones in which relatively valuable or sensitive species live, project planners can minimize changes within the biological community (Shields 1982, Shields and Palermo 1982).

Delineating aquatic habitats, then, may often be an important first step in estimating the effects of proposed projects. Habitats found in small streams, and in lakes, have been delineated and studied for a considerable number of years. Even here, however, habitat classifications are still undergoing changes. Habitats in larger rivers have only relatively recently been examined with the same intensity, and due to difficulties in sampling, our knowledge of them is much less complete (Baker, Killgore, and Kasul, in press). This is particularly unfortunate because large, navigable river systems are often intensively manipulated (e.g., the Lower Mississippi River) US Army Engineer District, Vicksburg 1976).

The habitats that are recognized depend upon the needs and objectives of the person or agency. Often, those concerned with managing long river reaches, or entire river systems, must define habitats using criteria that can be recognized and manipulated using procedures such as Geographic Information Systems (e.g., Cobb and Williamson 1989). Because of this, variables such as current speed, which are not identifiable from aerial photos or hydrographic surveys, cannot generally be used (e.g. Cobb and Clark 1981). However, the advantage of being able to rapidly assess the impact of river regulation activities on at least general ecosystem subunits (habitats) is important.

To be of the fullest use in predicting potential biological changes associated with alterations in the physical environment of the river, habitats

* US Army Engineer Waterways Experiment Station, Vicksburg, MS.

must be delineated as they are perceived by the organisms (Baker and Killgore 1989). Since we cannot in practice "know" what the organisms perceive, we must estimate habitat boundaries and delineate species preferences based on sampling, or make judgments based on studies in other, similar ecosystems. Either of these methods may introduce one or more sources of error, some of which may be considerable. In addition, there are seasonal effects, differences among species and life-history stages, and also perhaps year-to-year variations that make defining relevant habitats, and associating species with them, more complex.

Thus, to some extent the precise definitions of large river habitats may differ between engineers and ecologists. However, additional research may indicate ways in which their classifications can be integrated.

References

Baker, J. A., and Killgore, K. J. 1989. "Habitat Evaluation Methods Notebook; Habitat Classification of Lower Mississippi River Fishes: Selecting Evaluation Elements (Section 5e), Instruction Report EL-85-3, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Baker, J. A., Killgore, K. J., and Kasul, R. L. "Aquatic Habitats and Fish Communities in the Lower Mississippi River," CRC Reviews in Aquatic Sciences (in press).

Cobb, S. P., and Clark, J. R. 1981. "Aquatic Habitat Studies on the Lower Mississippi River, River Mile 480 to 530; Report 2, Aquatic Habitat Mapping," Miscellaneous Paper E-80-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Cobb, S. P., and Williamson, A. N. 1989. "Lower Mississippi River Environmental Program; Report 17, The Computerized Environmental Resources Data System (CERDS): A Geographic Information System for Environmental Data on the Leveed Floodplain of the Lower Mississippi River," Mississippi River Commission, Vicksburg, MS.

Ross, S. T. 1986. "Resource Partitioning in Fish Assemblages: A Review of Field Studies," Copeia 1986:352-380.

Shields, F. D., Jr. 1982. "Environmental Features for Flood-Control Channels," Water Resources Bulletin 18:779.

Shields, F. D., Jr., and Palermo, M. R. 1982. "Assessment of Environmental Considerations in the Design and Construction of Waterway Projects," Technical Report E-82-8, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

US Army Engineer District, Vicksburg. 1976. "Final Environmental Impact Statement--Mississippi River and Tributaries, Mississippi River Levees and Channel Improvement," Vicksburg, MS.

TECHNIQUES FOR EVALUATING AQUATIC HABITATS

SAMPLING DESIGN FOR RESERVOIRS

Robert F. Gaugush*

Reservoir Sampling Design

This presentation of the concepts of sampling design and its application to reservoir water quality studies was derived from:

> Gaugush, R. F. 1987. "Sampling Design for Reservoir Water Quality Investigations," Instruction Report E-87-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

This paper introduces the statistical concepts involved in the development of sampling designs for reservoir water quality investigations. It provides an overview of statistical inference and the assumptions involved in sampling. A discussion of basic statistics is included to familiarize the reader with the necessary statistical background for the material to follow. This discussion of the methods of sampling design is made with specific reference to reservoir water quality sampling and covers the determination of sample size, simple random sampling, stratified random sampling, and systematic sampling. Other topics include the use of decision matrices, tools to aid the decision-making process involved in determining the number of samples, the parameters to be measured, and the frequency of sampling within funding constraints. Reservoir water quality patterns and their implications for sampling design are discussed with emphasis on the influence of parameter frequency distributions, spatial patterns, and temporal patterns on sampling design. From the consideration of reservoir water quality patterns, a generalized sampling design is developed. Methods for the evaluation of an implemented sampling design are also considered. The techniques of variance component analysis, cluster analysis, and error analysis can be used to determine the effectiveness of a given sampling design.

Instruction Report E-87-1 has recently been reprinted, and copies can be obtained from the author at the address given at the conclusion of the paper.

---

* US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Sampling Design Software

A software package has been developed to assist in the determination of sample size and sampling design evaluation. Sampling Design Software (SDS) is a PC-based set of routines developed as a companion to the sampling design instruction report. SDS incorporates the following four routines:

- Decision matrices
- Variance component analysis
- Cluster analysis
- Error analysis

The first routine, decision matrices, allows the user to determine required sample sizes in a multivariable sampling program, by providing estimates of the mean and variance, the desired level of precision, and the acceptable probability of error.

The remainder of the SDS package deals with sampling design evaluation. Once the data have been collected from a reservoir water quality monitoring program, the data analysis phase of the study can be initiated. There are two fundamental types of data analysis: that directed at characterizing the reservoir's water quality, and that with the objective of analyzing the effectiveness of the sampling design. The second type of data analysis is rarely considered. Evaluation of the sampling design is an important task because if the design is to be used again (as in an ongoing monitoring program), it is essential to determine if the design can be improved to increase the precision of the estimates or reduce the cost of sampling. Even if the sampling will not be repeated, it is worthwhile to evaluate the effectiveness of the design to aid the development of future sampling programs.

The SDS package addresses three important questions about the effectiveness of the sampling design and provides a corresponding method to answer each of the questions:

1. How well does the sampling design "explain" or account for the observed variance?

   Method: variance component analysis

2. Are there redundancies in the data that can be removed to improve the sampling design?

   Method: cluster analysis

3. Can the sampling design be modified to improve the precision of the estimates?

   Method: error analysis

The software was developed and compiled using Turbo Pascal 5.5 and will run on any microcomputer using the MS-DOS operating system.

The sampling design software and a user's manual can be obtained by contacting the author:

US Army Engineer Waterways Experiment Station
ATTN: CEWES-ES-A (Robert F. Gaugush)
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Telephone: (601) 634-3626

SAMPLING TECHNIQUES FOR FRESHWATER MUSSELS

Andrew C. Miller*

Introduction

Freshwater mussels, a resource with economic, ecological, and cultural value, often comprise a major component of the benthic biomass in medium-sized to large rivers, ponds, lakes, and reservoirs. Because they are long lived, have a sedentary life style, and rely on particulate organic matter for food, they are usually considered indicators of clean water (Fuller 1974). Currently, 25 species are listed as endangered (US Fish and Wildlife Service 1987), and numerous others are protected by State conservation agencies.

There are approximately 31,000 species of bivalve molluscs, which are characterized by the presence of two calcareous valves united by an elastic hinge ligament. The majority of these organisms (including the freshwater unionids of this country) belong to the subclass Lamellibranchia, which are characterized by having two enormously enlarged gills used for feeding (Russell-Hunter 1979). Water currents are created by lateral cilia that flow through gill filaments. Suspended material then accumulates on the inhalant faces of the gill lamellae. Particulate matter is either carried to the mouth or directed to the edges of the palps, where it is ultimately ejected as pseudofeces. Although numerous workers have stated that freshwater molluscs are particularly susceptible to suspended sediments and sedimentation (Stansbery 1971), it must be remembered that these organisms are adapted to feed in turbid water and to sort unsuitable particles from fine-grained organic matter.

Freshwater mussels are dioecious and produce large numbers of eggs that, when fertilized, give rise to specialized parasitic larvae called glochidia. Glochidia are expelled through the excurrent siphon and must attach to a host (usually a fish) for a development period. Some species of mussels appear to require a single host species; other are fairly general in their host requirements (see Fuller 1974).

Both their feeding mechanisms and their manner of early development indicate that the majority of mussel species should inhabit large rivers with

---

* US Army Engineer Waterways Experiment Station, Vicksburg, MS.

moderate flow. In addition, areas along the shoreline which exhibit moderate sedimentation can be particularly suitable for mussels. Additional information on the biology and ecology of freshwater mussels can be found in Russell-Hunter (1979).

Developing a Sampling Program for Freshwater Mussels

Before a survey for mussels is initiated, background information on study sites should be obtained. Minimum, maximum, and average values for discharge and stage height should be obtained from the Corps or the US Geological Survey (USGS). USGS topographic maps, local county maps, or aerial photographs should be consulted to identify access points and to mark study sites. The likelihood of finding mussels in the study area can often be determined from fishermen.

Biologists and planners in Federal and State agencies are likely to conduct three types of mussel surveys:

1. A reconnaissance survey to determine the presence or absence of live mussels or shells at a specific site or river reach.
2. A detailed investigation at sites where mussels are likely to occur.
3. A long-term monitoring study with the objective of collecting information on important biotic parameters (density, species richness, etc.) at regular intervals.

The following describes objectives, equipment, and personnel requirements for these types of surveys. Additional information on techniques for sampling freshwater mussels can be found in Coker (1918), Parmalee (1967), Starrett (1971), Brice and Lewis (1979), Buchanan (1980), Miller and Nelson (1983), and Miller and Payne (1988). Data on physical or chemical conditions that should be assessed (regardless of the type of survey to be conducted) can be found in Salmon and Green (1983) and Strayer (1983).

Reconnaissance Survey

Reconnaissance without divers

A preliminary investigation using a minimum of equipment and personnel should be conducted before more detailed studies are initiated. This can be accomplished without divers in shallow water or along the margin of large rivers or lakes. The objectives of this type of survey would be to establish if live mussels are present, to identify areas where more study is required, and to obtain information on existing physical and chemical conditions. One outcome of a preliminary investigation might be that no more work is required.

Two or three individuals and a small boat can examine 5 to 10 river miles in a single day. Distance covered depends upon the number of stops for collection and the need to portage over shoals or snags. A 12-ft flat-bottom boat with 7.5- or 9.9-hp motor is useful if the water is shallow and river access poor. A 14- or 16-ft boat and 35-hp motor is appropriate for more than two people and their equipment. The late summer or early fall is the best time to conduct this type of survey since water levels are low and visibility is usually good. Exposed shoals or gravel bars are the best places to spot shells, although shells can be left virtually anywhere by raccoons or high water. A viewing box, which can be easily built by replacing the bottom of a plastic bucket with Plexiglas, will improve underwater visibility. A rake, shovel, or hand-held dipnet can be used to locate shells or live mussels in shallow water.

A small brail (with a bar 2 to 4 ft long) can be easily operated by one person from the bow or stern of a boat (see Miller and Nelson 1983 for details). The brail was developed by commercial shell fishermen and consists of a bar with a series of pronged hooks that snag live mussels. Shells can be stored in buckets, heavy-duty garbage bags, or gallon-sized zipper-lock bags. Live specimens can be kept in buckets or preserved in 10-percent buffered formaldehyde. Sites where live mussels or shells are found should be marked on topographic maps for future investigation.

Reconnaissance with divers

If large numbers of fresh shells or live mussels are found during the preliminary survey, a more detailed investigation with divers may be necessary. This is particularly important if study sites are within the range of an endangered species, or if a proposed water resource project is likely to disrupt valuable mussel habitat. Although it is fairly easy to obtain certification to dive at a local sports shop or the YMCA, we have had best success with trained dive crews. The Tennessee Valley Authority and US Army Corps of Engineers, as well as many salvage companies, typically have dive crews that can be used for surveys. The crew usually consists of a leader, a tender, and one or more divers. A dive crew can cost from $1,000 to $2,000 a day. It is preferable to hire divers that normally work together, rather than attempting to assemble a team of individual divers. Large rivers are much more dangerous than they appear, and biologists or students that have recently completed a recreational dive class do not have the experience to work safely in these areas. It is more efficient to have one or more biologists on the surface processing samples, locating sites, and recording data, and to leave the diving to those with experience.

Surface air supply with communications equipment is usually preferred over scuba (self-contained underwater breathing apparatus). Information on substrate type, presence of mussels, physical conditions, etc., can be transmitted to the surface quickly by one or more divers. The surface crew can orient the divers and help to ensure a safe working environment. Scuba tanks allow for maneuverability, but they are cumbersome and must be frequently filled or else a sufficient number must be available.

The dive boat should be anchored (using at least a bow and stern anchor) at a site where mussels are likely to be found. One or more divers should be sent to the bottom to determine if mussels are present. If mussels are present, the diver should provide an estimate of density (i.e., the approximate number of mussels in a square yard or meter). In addition, divers should obtain information on substrate type, water velocity, and visibility.

If mussels are present, the site can be marked with a buoy. If appropriate, the approximate size of the bed can be estimated by a series of reconnaissance dives. Depending on the speed at which divers can get in and out of the water and the difficulty of repositioning boats, 3 or 4 hr may be required. Depending on the objectives of the survey, it might be useful to move on and conduct preliminary investigations at other sites before detailed studies are initiated. This would help ensure that time and funds are not wasted on sites that are not as productive as was first thought.

Detailed Surveys with Divers

Divers can be used for three types of studies: (1) qualitative, (2) semiquantitative, or (3) quantitative. The following describes techniques for conducting these surveys and provides examples of the types of information that can be obtained.

Qualitative survey

A qualitative collection should include representative numbers and sizes of all species. Obviously this is difficult to achieve, especially in deep water where visibility is poor and divers collect strictly by touch. However, qualitative collections can be taken more quickly than quantitative ones, and they may be preferred if the objective is simply to prepare a species list or to determine if rare or endangered species are present. However, qualitative sampling often misses small species or individuals and can be biased toward large, commercially valuable species. Past experience of the diver often influences the quality of the data. Often a diver will unknowingly concentrate on common, very small, very large, or unusual organisms.

A qualitative collection can be obtained by having a diver collect all live mussels that are either seen or felt. It is useful to record the time spent underwater since this provides a method for comparing sites. This will provide data on the number of mussels collected per unit of time, as well as the relative species abundance. An example of the type of data obtained from a qualitative survey appears as Table 1 (page 48).

Additional information can be obtained if mussels are collected in small groups of about 20 individuals. Depending on density, a diver can collect two to four bags of 20 mussels in an hour. If 8 to 10 bags are obtained, the total collection will usually include uncommon specimens (that comprise at least 0.5 to 1 percent of the assemblage) but probably not the most rare organisms. These data can be used to prepare a species-area curve that graphically depicts the ability to obtain rare species (see also Isom and Gooch 1986; Kovalak, Dennis, and Bates 1986; Miller and Payne 1988). Regression lines with a steep slope have high richness with respect to total individuals present (Figure 1). Typically, we collect about 200 mussels at a site using this technique, although up to 1,000 specimens should be obtained if it is likely that a rare species is present. One to two biologists can identify specimens and record data on standard sheets (Table 2).

Semiquantitative survey

This type of survey requires collecting all mussels encountered by touch (or visually, if possible) within a premeasured area. The survey area could range from 1 square meter up to tens of square meters. Alternatively, a transect can be established between two points with a weighted rope or cable. The rope can be divided into 10-m sections with weights. The diver swims or crawls slowly and collects all mussels on either side (within 1 m) of the rope. The approximate area on either side of the rope that each diver can work comfortably should be determined before sampling begins. Mussels from each 10-m section are separated and held in nylon dive bags. These data provide an estimate of density and relative species abundance at different locations in a mussel bed. Quantitative samples for mussels (see below) can also be obtained along a transect (Figure 2).

Both of these methods (searching along a transect and collecting in a premarked area) provide estimates of density and community composition quickly. In addition, they provide a species list and a table of relative species abundance. However, small species and individuals can be missed using these methods. Finally, it is time-consuming to mark a large area in deep water. Laying a weighted line with two boats requires skill and patience, and decreases the time available for collecting.

Quantitative survey

Obtaining a quantitative mussel collection requires removing all substrate from a specific area and sending it to the surface. A 0.25-m^2 quadrat, made from 1/8-in. aluminum stock, is the most convenient size for a diver to use. Larger quadrats (1.0 m^2 or 5 × 5 ft) have been used by other workers; however, we consider this size too cumbersome. Approximately 20 ℓ of substrate will be obtained if the quadrat is excavated to a depth of about 10 cm. The substrate is taken to shore and sieved through a screen series. Live mussels are removed by hand, and either preserved or returned to the laboratory alive. We usually obtain two to three sets of ten 0.25-m^2 samples at each site to avoid pseudoreplication (Hurlbert 1984). Two or more sites (i.e., inshore, offshore, or upriver/downriver) can be sampled in about 3 days with an experienced crew.

In the laboratory, all mussels are identified and weighed, and the total shell length is measured. A quantitative survey provides information on evidence of recent recruitment, population structure (Payne and Miller 1989), relative species abundance, density, species richness, and species diversity. All of these parameters are important for assessing the value of aquatic habitats. Data obtained from these studies provide information that should be a part of environmental studies conducted by the Corps of Engineers.

Monitoring Studies

Depending on the objective of the survey, it may be important to monitor changes in important biotic parameters (species richness, species diversity, density, relative species abundance, etc.) through time. A combination of qualitative and quantitative surveys can be used. Adequate information on mussels can be obtained by conducting a survey every other year during the same season (usually the fall). A successful monitoring program depends upon careful attention to site selection, use of appropriate techniques, and sampling under similar conditions of water depth and velocity.

References

Brice, J., and Lewis, R. 1979. "Mapping of Mussels (Unionidae) Communities in Large Streams," American Midland Naturalist 101:454-455.

Buchanan, A. C. 1980. "Mussels (Naiades) of the Meramec River Basin, Missouri," Aquatic Series No. 17, Missouri Department of Conservation, Jefferson City, MO.

Coker, R. E. 1918. "Freshwater Mussels and Mussel Industries of the United States," Bulletin of the Bureau of Fisheries 36:11-89.

Fuller, S. L. H. 1974. "Clams and Mussels (Mollusca:Bivalvia)," Pollution Ecology of Fresh-Water Invertebrates, C. Hart and S. L. H. Fuller, eds., Academic Press, New York, pp 215-273.

Hurlbert, S. H. 1984. "Pseudoreplication and the Design of Ecological Field Experiments," Ecological Monographs 54:187-211.

Isom, B. G., and Gooch, C. 1986. "Rationale and Sampling Design for Freshwater Mussels, Unionidae, in Streams, Large Rivers, Impoundments, and Lakes," Rationale for Sampling and Interpretation of Ecological Data in the Assessment of Freshwater Ecosystems, ASTM STP 894, B. G. Isom, ed., American Society for Testing and Materials, Philadelphia, PA.

Kovalak, W. P., Dennis, S. D., and Bates, J. M. 1986. "Sampling Effort Required to Find Rare Species of Freshwater Mussels," Rationale for Sampling and Interpretation of Ecological Data in the Assessment of Freshwater Ecosystems, ASTM STP 894, B. G. Isom, ed., American Society for Testing and Materials, Philadelphia, PA.

Miller, A. C., and Nelson, D. A. 1983. "An Instruction Report on Freshwater Mussels," Instruction Report EL-83-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Miller, A. C., and Payne, B. S. 1988. "The Need for Quantitative Sampling to Characterize Size Demography and Density of Freshwater Mussel Communities," Bulletin of the American Malacological Union 6:49-54.

Payne, B. S., and Miller, A. C. 1989. "Growth and Survival of Recent Recruits to a Population of *Fusconaia ebena* (Bivalvia Unionidae) in the Lower Ohio River," American Midland Naturalist 121:99-104.

Parmalee, P. W. 1967. The Fresh-water Mussels of Illinois, Popular Science Series, Vol 8, Illinois State Museum, Springfield, IL.

Russell-Hunter, W. D. 1979. A Life of Invertebrates, Macmillan, New York.

Salmon, A., and Green, R. H. 1983. "Environmental Determinants of Unionid Clam Distribution in the Middle Thames River, Ontario," Canadian Journal of Zoology 61:832-838.

Starrett, W. C. 1971. "A Survey of the Mussels of the Illinois River: A Polluted Stream," Illinois Natural History Survey Bulletin 30:267-403.

Stansbery, D. H. 1971. "Rare and Endangered Mollusks of the Eastern United States," Proceedings of a Symposium on Rare and Endangered Mollusks (Naiads) of the United States, Jorgensen and Sharp, eds., US Department of the Interior, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, pp 5-18.

Strayer, D. 1983. "The Effects of Surface Geology and Stream Size on Freshwater Mussels (Bivalvia, Unionidae) Distribution in Southeastern Michigan, U.S.A.," Freshwater Biology 13:253-264.

US Fish and Wildlife Service. 1987. "Endangered and Threatened Wildlife and Plants," Federal Register, 10 April 1987 (50 CFR 17.11 and 17.12).

Table 1

Mussels Collected in Riprap at Four Bridges on the St. Francis Floodway, St. Francis and Lee Counties, Arkansas, 18-19 August 1987

	River Mile						
	28.0		31.0		33.0		
Species	22.0	LDB	RDB	LDB	RDB	LDB	Total (%)
Leptodea fragilis (Rafinesque, 1820)	291	227	130	283	129	19	63.58
Potamilus purpuratus (Lamarck, 1819)	43	46	40	63	32	4	13.43
Potamilus capax (Green, 1832)	26	20	20	22	9	8	6.19
Lampsilis teres (Rafinesque, 1820)	6	6	4	14	24	6	3.53
Amblema plicata (Say, 1817)	-	-	5	37	-	-	2.47
Tritogonia verrucosa (Rafinesque, 1820)	2	3	10	21	5	-	2.42
Megalonaias gigantea (Barnes, 1823)	-	3	15	11	-	-	1.71
Obliquaria reflexa (Rafinesque, 1823)	-	2	3	21	-	2	1.71
Quadrula pustulosa (Lea, 1831)	1	2	3	21	-	1	1.65
Quadrula quadrula (Rafinesque, 1820)	-	2	4	11	4	2	1.35
Anodonta imbecillis (Say, 1829)	2	-	-	3	3	-	0.47
Anodonta grandis (Say, 1829)	-	1	2	2	-	-	0.29
Lasmigona complanata (Barnes, 1823)	-	1	2	2	-	-	0.29
Potamilus laevissima (Lea, 1830)	-	-	4	-	-	-	0.23
Quadrula nodulata (Rafinesque, 1820)	-	1	-	2	-	1	0.23
Fusconaia flava (Rafinesque, 1820)	-	-	1	1	-	-	0.12
Truncilla truncata (Rafinesque, 1820)	-	1	1	-	-	-	0.12
Arcidens confragosus (Say, 1829)	-	-	-	-	1	-	0.05
Lampsilis radiata siliquoidea (Barnes, 1823)	-	1	-	-	-	-	0.05
Ptychobranchus occidentalis (Conrad, 1836)	-	-	-	-	1	-	0.05
Total mussels	371	316	244	514	208	43	1696
Total species	7	14	15	15	9	8	20
Mussels/meter of shoreline	3.2	4.8	2.7	4.7	3.0	1.9	
Mussels/individual/hour	53	45	30.5	64.4	34.7	10.7	

Note: LDB = left descending bank; RDB = right descending bank.

Table 2

Field Data Sheet for Recording Results of Qualitative Mussel Collections

Location ____________________

Filename: ________

Date ____________

Collection No. ________ RM: _____ DEP: _____ DST: _______ LDB: ___ RDB: ____

Notes:

Notes:

Numb Samples: ________ Sheet ___ of ____

Species	S1	S2	S3	S4	S5	S6	S7	S8	S9
A. plicata									
T. donaciformis									
L. fragilis									
P. alatus									
Q. quadrula									
T. truncata									
A. confragosus									
M. gigantea									
O. reflexa									
A. grandis									
Q. nodulata									
A. corpulenta									
Q. pustulosa									
T. parvus									
E. lineolata									
C. fluminea									
F. flava									
L. ventricosa									
O. olivaria									
P. laevissima									
L. recta									
S. undulatus									
L. higginsi									
L. complanata									
E. dilatata									
L. teres									
P. pyramidatum									
Q. metanevra									
A. ligamentina									
L. radiata radiata									
C. monodonta									
F. ebena									
A. imbecillis									
A. suborbiculata									
Total individuals									
Cum. individuals									
Total species									
Cum. sp.									
Ind./sp.									

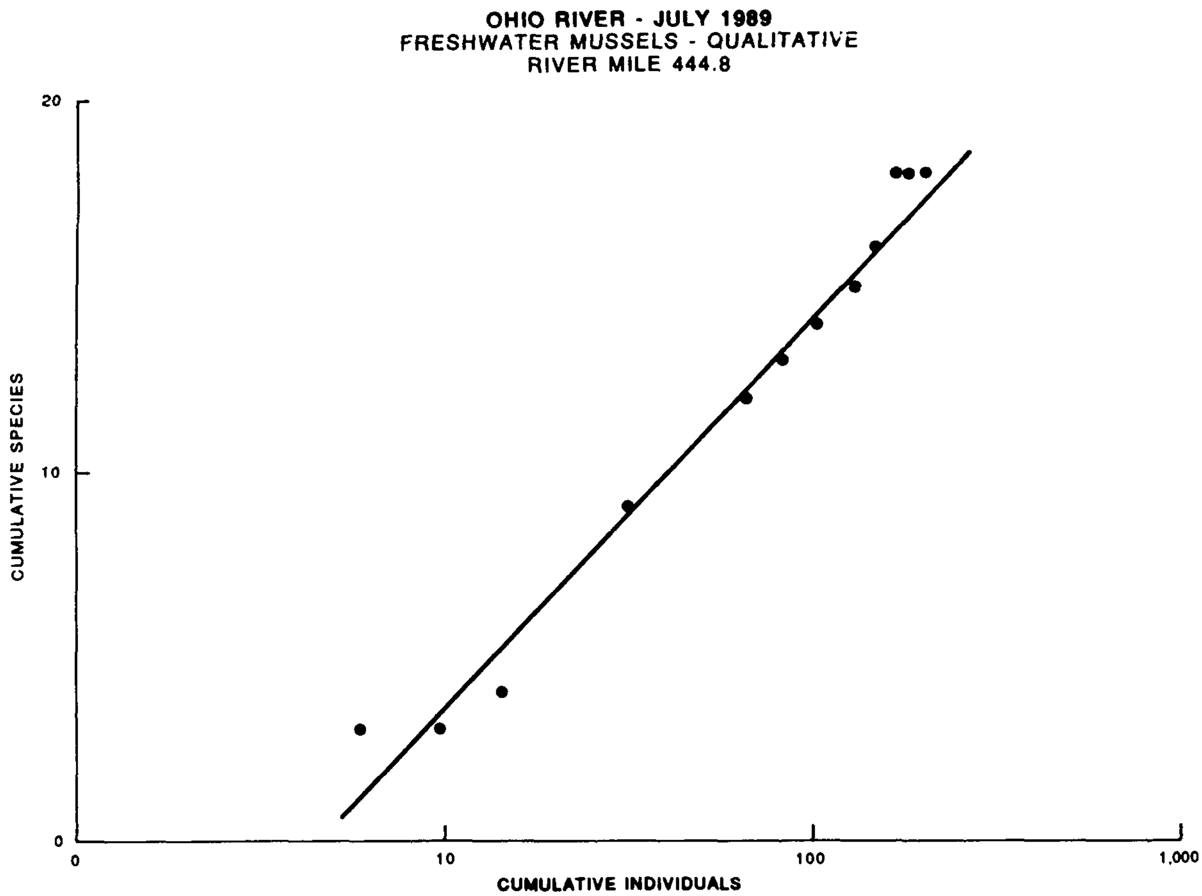


Figure 1. Relationship between cumulative species (Y) and $\log_e$ cumulative individuals (X) for a site surveyed in the Ohio River, river mile 444.8, 1989

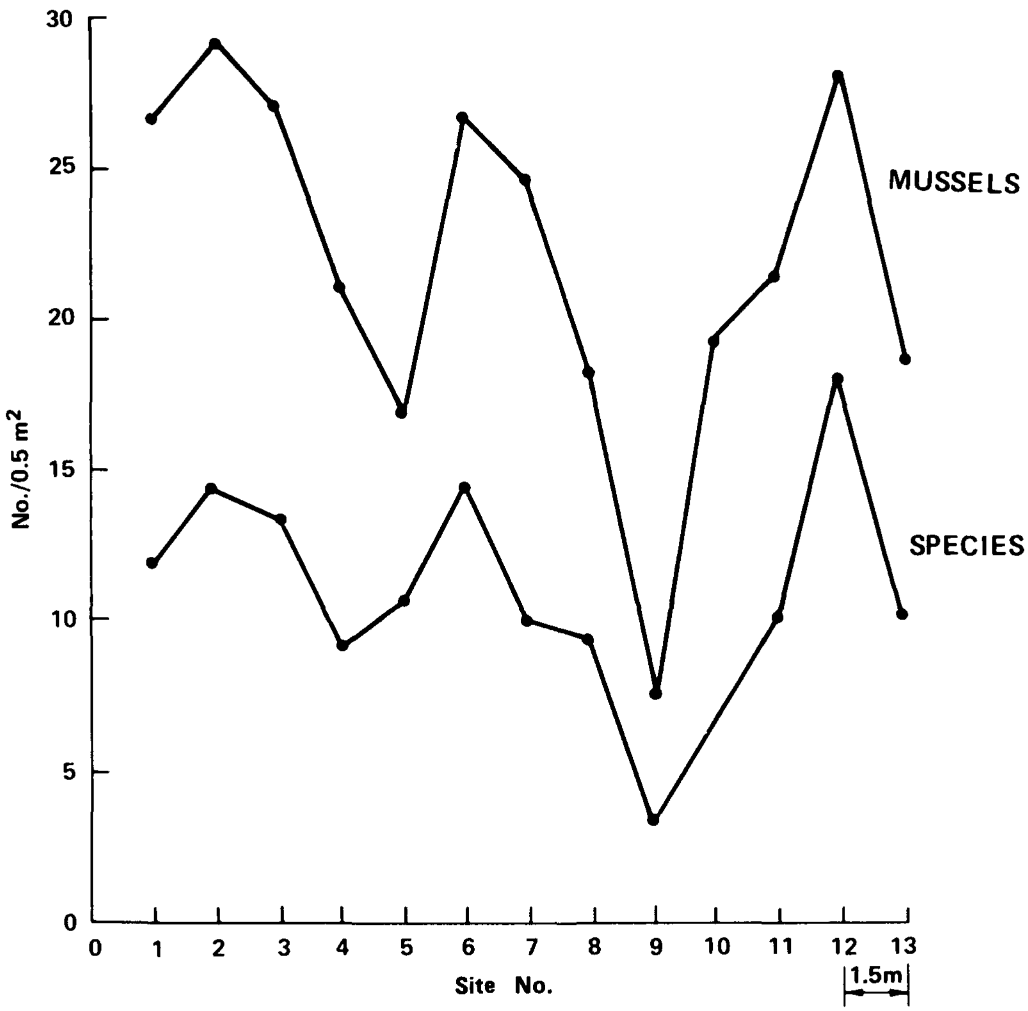


Figure 2. Total species and total individuals collected in two 0.25-m^2 quadrats along a transect in the upper Mississippi River near Prairie du Chien, WI (from Miller and Payne 1988)

ECOLOGY AND SAMPLING OF FRESHWATER INVERTEBRATES

David C. Beckett*

Ecology of Freshwater Invertebrates

When people consider aquatic habitats, and the animals within aquatic habitats, they generally think of fishes. Indeed, when most people think of "animals" they think of vertebrates such as mammals, or perhaps birds, reptiles, amphibians, or fishes. In reality, the overwhelming majority of animals on our planets are invertebrates, animals without backbones. There are 31 animal phyla in existence on Earth; 30 of these consist entirely of invertebrates (Arms and Camp 1987). About 97 percent of all the known animal species are invertebrates (Barth and Broshears 1982).

In freshwater habitats the fishes are vastly outnumbered by invertebrates in terms of both density and diversity. Invertebrate densities $>10^5$ individuals per square meter of substrate are fairly common in freshwater habitats (Fisher 1982), and mean densities of $>10^6$ invertebrates per square meter of substrate have been reported from sandy substrates in the bottom of the Mississippi River (Aartila 1988). Invertebrate communities are also much more diverse than fish communities. For example, the state of Missouri, which supports a relatively diverse fish fauna, contains a total of a little less than 200 fish species (Pflieger 1975). In contrast, a single family of insects--the Chironomidae (a Dipteran family)--often numbers more than 100 species in a single natural pond, lake, or stream (Coffman and Ferrington 1984).

The dominant invertebrate groups in fresh water are the oligochaetes, molluscs, crustaceans, insects, and nematodes. The two most common oligochaete families are the Tubificidae and the Naididae. The tubificids are members of the infauna, animals that live in the bottom sediments. The tubificids burrow head down in the sediments, often with some portion of the posterior of the worms projecting above the sediment-water interface. Tubificids are the freshwater analogues of earthworms; these freshwater worms ingest silt and clay particles, and in doing so mix the sediments. Naidids are smaller in

* Department of Biological Sciences, University of Southern Mississippi, Hattiesburg, MS.

size than the tubificids, and while some naidid species live on the bottom of aquatic habitats, other naidid species live on objects in the water column. Naidid worms are one of the most common invertebrate groups on freshwater macrophytes.

The molluscs consist of gastropods (snails) and bivalves (clams). Snails are quite ubiquitous in freshwater environments; they are found in small ponds and streams, as well as in very large lakes and rivers. The most diverse bivalve communities are present in medium- to large-sized rivers. The large rivers of the Mississippi River drainage have (or perhaps had) an especially rich bivalve fauna, which includes many members of the bivalve family Unionidae. Unfortunately, the larger rivers of the United States have been heavily impacted by anthropogenic activities, and the pollution, impoundment, and siltation of these rivers coupled with the overharvesting of bivalves has decimated many bivalve communities.

Although the overwhelming majority of crustaceans are marine, a diverse assortment can be found in fresh water. These crustaceans include fairy, tadpole, and clam shrimp; cladocerans (water fleas); copepods; ostracods (seed shrimp); opposum shrimp; isopods; amphipods; crayfish; grass shrimp; and river shrimp. In North America, isopods are most common in small streams where they feed in leaf packs and on the underside of rocks. Blind, pigmentless isopods occupy some cave streams and hypogean waters. Amphipods are frequently found in streams as well as in the littoral zone of lakes. Crayfish, which serve as food for some fishes, and are themselves omnivores, have been found to be important in determining the densities of macrophytes and the abundance of other invertebrate species in some Wisconsin lakes (Lodge, Beckel, and Magnuson 1985).

Thirteen of the approximately 30 to 35 orders of insects have representatives in fresh water (Daly 1984). Only five of the orders--the Ephemeroptera (mayflies), Plecoptera (stoneflies), Odonata (dragonflies and damselflies), Trichoptera (caddisflies), and Megaloptera (alderflies, dobsonflies, and fishflies)--consist of members in which almost all their species are aquatic during at least one stage of their life cycle. In each of these five orders the immatures are aquatic while the adults are terrestrial. The order Diptera (true flies) is very important in freshwater systems. In North America, 29 dipteran families have aquatic representatives, the most abundant of which is the family Chironomidae. There are approximately 2,000 species of chironomids in the Nearctic Region, most of which are aquatic (Coffman and rrington 1984). Chironomids occupy virtually all types of microhabitats and trophic roles in aquatic situations; they typically account for about half of the total number of invertebrate species present in aquatic systems. Because of their great diversity, abundance, and wide array of environmental preferences, chironomids have been used as indicators of the trophic status of lakes (Brundin 1958, Saether 1975) and as indicators of pollution (Simpson and Bode 1980, Beckett and Keyes 1983).

Nematodes are both ubiquitous and abundant in fresh water. Collections of sediment, detritus, or plant material from virtually all aquatic ecosystems contain nematodes. However, despite their abundance, nematodes have generally been avoided by researchers, probably due to their relatively small size and difficulties with their identification (Pennak 1978).

From an anthropocentric viewpoint, aquatic invertebrates have been both a blessing and a curse. Massive emergences of adults of aquatic insects have been both a nuisance and a cause of health problems. Hynes (1984a) describes great clouds of the adults of the phantom midge *Chaoborus* that form over Africa's Lake Victoria; when the wind is right the phantom midges are blown ashore and blanket the town of Entebbe, Uganda. Massive emergences of the burrowing mayfly *Hexagenia* have even halted traffic as the bodies of the short-lived adults piled up on bridges and roads near rivers or lakes. Burks (1953) cites a July 23, 1940, dispatch from the Associated Press:

> Sterling, Illinois--Shadflies [actually mayflies] that in some places piled to a depth of four feet blocked traffic over the Fulton-Clinton highway bridge for nearly two hours last night.
>
> Fifteen men in hip boots used shovels and a snow plow to clear a path. The bridge appeared to be covered with ice and snow. Trucks without chains were unable to operate until most of the flies had been shoveled into the Mississippi river.

Other examples of nuisances caused by mass emergences of aquatic insects include swarms of hydropsychid caddisflies vexing cities along the Mississippi River (Fremling 1960) and large numbers of moth flies (Psychodidae) emerging from sewage treatment plants (Hynes 1984b).

A number of aquatic insect species are important from a medical standpoint, the most notable of which are the mosquitoes in the genera *Anopheles*, *Aedes*, and *Culex*. Malaria is transmitted by *Anopheles* spp.; yellow fever, dengue, and types of encephalitis are transmitted by species of *Aedes*. Certain species of *Culex* transmit filariasis (which is caused by nematodes), as well as encephalitis. Some species of black flies (Simuliidae) and tabanids

(Tabanidae, horse flies and deer flies) transmit nematodes that cause filarial diseases in humans. In addition to the possibility of causing diseases, adult mosquitoes, black flies, and tabanids are very serious pests. At times, mosquitoes and black flies make things especially unpleasant for humans, livestock, and wild animals in Maine, Canada, and Alaska; some deaths in humans have even been reported as a consequence of excessive bites from flies (Laird et al. 1982). Allergic reactions have occurred in Africans as a result of exposure to massive numbers of adult chironomids (Rzoska 1976); similarly, the adult hydropsychid caddisflies originating from the Mississippi River cause allergic reactions in some residents of nearby towns (Fremling 1960).

Aquatic invertebrates make positive contributions as well. Early investigators of aquatic invertebrates often regarded them and referred to them as "fish food organisms." Although they are certainly more than just that, there is no doubt that invertebrates make up a substantial portion of the diet of many fishes. Among the earliest animal foods to be consumed by fishes are zooplankton (Lagler et al. 1977). Although the larval stages of some insects and fishes are planktonic, the bulk of the zooplankton consists of rotifers, copepods, and cladocerans. Even after they pass the larval stage, many fish species are dependent on invertebrates as a food source. For example, aquatic invertebrates comprise most of the diet of the young members of the three large catfish species of the Mississippi River drainage: the channel, blue, and flathead catfishes (Pflieger 1975). As these catfishes grow, larger invertebrates such as crayfish make up a substantial portion of their diet. Invertebrates constitute an important food source in a number of other "sought-after" freshwater fishes. A partial list includes largemouth, smallmouth, and spotted bass; bluegill, green sunfish, and other sunfishes; walleye; and rainbow and brown trout (Pflieger 1975). Of course, many nongame fishes eat freshwater invertebrates as well.

Anglers, in their own way, pay homage to aquatic insects. The "wet flies" they use to catch fishes are mimics of insect nymphs or larvae, while "dry flies" are mimics of adults or subadults of various orders of aquatic insects.

A number of other animals besides fishes feed on aquatic invertebrates. Aquatic invertebrates are an important part of the diet of waterfowl (Krull 1970). Swanson, Meyer, and Serie (1974) discussed the increased use of aquatic insects by blue-winged teal as the breeding season arrived. Many swallows "buzz" the surface of streams and ponds, feeding on the emerging aquatic insects. Other vertebrates, including newts, salamanders, small crocodiles, and several mammals that live near fresh water, also feed on aquatic invertebrates (Hynes 1984b). Even humans occasionally feed on freshwater invertebrates. Crayfish are eaten as gourmet items, and are raised as a crop in ponds in the southeastern United States. In central Africa, adult phantom midges are gathered by natives and made into cakes for human consumption; in Mexico, two species of water boatmen (Insecta: Hemiptera: Corixidae) are cooked and eaten by humans (Hynes 1984b).

Freshwater invertebrates are very important in the conversion of energy in aquatic systems; that is, they do much more than merely serve as the prey of fishes. Just as invertebrates can be classified along systematic lines, they can also be classified according to their functional role in the processing of organic matter in aquatic habitats. This view gives insight as to the flow of energy through freshwater environments. For example, Fisher (1982) has proposed the following classification scheme for invertebrates feeding in the bottom of ponds or lakes:

- Suspension feeding--removing food material from suspension in the water mass without the need to subdue or dismember particles; examples = unionid and sphaerid bivalves.
- Deposit feeding--removing food from sediment either selectively or nonselectively without the need to subdue or dismember particles; examples = oligochaetes, amphipods, chironomids.
- Browsing--acquiring food by scraping plant materials from environmental surfaces or by chewing or rasping larger plants; examples = gastropods, chironomids, crayfish.
- Carnivory--actively capturing and subduing prey; examples = leeches, chironomids, crayfish.
- Scavenging--consuming large particles of dead organisms; examples = isopods, chironomids, crayfish.
- Parasitism--obtaining nutrition from the fluids or tissues of host organisms.

In a similar manner the trophic relations and functional feeding groups of invertebrates can be defined for streams and rivers as well as for lentic systems (see Cummins and Merritt 1984 and Lamberti and Moore 1984 for more information).

Sampling Freshwater Invertebrates

An important decision to be made before sampling can commence is the mesh size of the net or sieve to be used in processing samples. Largely because of the concept of invertebrates as "fish food organisms," early invertebrate studies focused on the larger invertebrates which made up most of the invertebrate biomass; thus, the mesh openings of nets and sieves tended to be rather large. The US Standard No. 30 sieve (mesh openings = 0.595 mm) became the standard for aquatic invertebrate studies. The US Environmental Protection Agency even went so far as to add sieve size to its definition of aquatic macroinvertebrates, stating that they are "animals that are large enough to be seen by the unaided eye and can be retained by a U. S. Standard No. 30 sieve" (US Environmental Protection Agency 1973). However, aquatic invertebrates vary widely in size, and there is no distinction along the range of sizes that can serve as a clear cutoff regarding minimum size. In addition, invertebrates grow as they mature, and a certain size sieve may allow early instars of an invertebrate species to pass through while collecting older, larger instars. Recognizing that the US Standard No. 30 sieve allowed many invertebrates to pass through the sieve uncollected, the US Geological Survey has recommended the US Standard No. 70 sieve (openings = 0.210 mm) for use in retaining invertebrates (Greeson et al. 1977).

It has become increasingly more obvious that the mesh openings of the sampling devices should be tailored for the purposes of the particular study. For example, studies of the invertebrates living in sandy substrates have shown that these animals are quite small; as a consequence, Barton and Smith (1984) have recommended that studies of invertebrates in such habitats should use sieves with openings of 0.100 mm or less. Unfortunately, although the use of finer sieves increases the possibility of gaining a realistic assessment of the number and identities of invertebrates present in a sample, mesh that is too fine can clog, and organisms can be lost by backwash. In addition, finer mesh sizes tend to retain substrate along with the invertebrates, complicating the separation of the invertebrates from the abiotic components in the sample.

Investigators often make use of the unidirectional flow of rivers and streams to collect invertebrates. Kick net sampling can be used to make semiquantitative collections of invertebrates. In this type of sampling a net is held just downstream, while invertebrates are dislodged by kicking or otherwise disturbing the stream substrates. In an effort to make their samples more quantitative, investigators often encompass a known area of stream bottom using a Surber or Hess sampler. The Surber sampler is a net with a square metal frame that rests on the stream bottom and has a net affixed to the back. The invertebrates on substrates within the frame are dislodged or cleaned off the substrates by brushing, and the animals are swept by the current into the net. The Hess sampler works in an analogous fashion except that the stream bottom is encompassed by an open cylinder that extends above the surface of the water. The person collecting the sample places his arms into the cylinder from above and brushes or dislodges the invertebrates off the substrates within the cylinder.

Obviously, the kick net and Surber and Hess samplers are useful only in shallow water. In deeper lotic systems and in lakes and ponds, benthic (bottom-dwelling) invertebrates are usually collected using either grab samplers or corers. Grab samplers are devices that bite into the bottom from above; they are triggered by spring and/or gravity-activated mechanisms. One of the most popular grab samplers is the Ekman grab. It is lightweight and is therefore portable, and can be operated by hand. Unfortunately, it works well only in soft sediments and in the absence of a strong current. The Petersen and Ponar grab samplers can sample firmer substrates than the Ekman. Although the standard Petersen and Ponar samplers are usually coupled with a winch to bring samples to the surface, a petite Ponar is available that can be easily manipulated by hand. Although the Petersen and Ponar samplers operate well in slight currents, stronger current velocities cause these samplers to contact the bottom at an angle rather than perpendicularly, and thereby operate ineffectively. High-energy habitats such as the lower Mississippi River necessitate the use of the Shipek grab sampler; this heavy and powerful sampling device contacts the bottom perpendicularly regardless of strong currents and is capable of taking grabs out of firm substrates such as sand and gravel or compacted clay (Bingham et al. 1982).

Coring devices can also be used to sample the benthic invertebrates of lotic or lentic systems. The use of corers rather than grab samplers provides several advantages. Core samples can be separated into several depth fractions, thereby furnishing a profile of the vertical distribution of benthic invertebrates. In addition, core samples usually contain a smaller amount of material than do grab samples. This reduces the per-sample processing time and allows for higher numbers of replicate samples to be processed. On the negative side, since core samples are smaller than grab samples, they present a much smaller "picture" or assessment, per sample, of the distribution and abundance of invertebrates. In addition, coring devices can be quite difficult to use in high-energy freshwater environments.

Researchers are increasingly using scuba divers in experiments requiring observation or manipulation of substrates or predator densities. Divers are capable of operating efficiently even in environments with no visibility and with strong current velocities. such as the bottom of the Ohio and Mississippi Rivers. For example, Payne and Miller (1988) were able to accurately determine the demographics of a mussel population in the Ohio River by using divers who placed grids of known area on the river bottom and then removed all the material, including mussels, from designated cells within the grids. Such a demographic assessment would not have been possible if only conventional mussel sampling techniques such as brailing had been employed.

In addition to the invertebrate fauna inhabiting the bottoms of lakes and streams, there are other invertebrate species that live on the clean surfaces of objects present in the water column. These surfaces include macrophytes, logs, rocks, the surfaces of other animals, and man-made objects. Simpson and Bode (1980) have used the term epibenthic to characterize these animals and have described them as "occurring on, but not penetrating, the substrate and submerged objects." Although such substrates and their invertebrate inhabitants can be sampled directly, the epibenthic community is often sampled using artificial substrates. Cairns (1982) has defined an artificial substrate as a "device placed in an aquatic ecosystem to study colonization by indigenous organisms. Although the device <u>may</u> be unnatural in composition, location, or both, most of the biological processes that occur on it appear to be quite similar to those occurring on natural substrates."

Artificial substrates are very useful in that identical microhabitats are difficult to find in nature, and biotic differences along a river or stream may be a function of differing microhabitats rather than a difference in the parameter of interest, such as water quality. Identical artificial substrates present uniform microhabitats, and, in addition, may be placed precisely wherever the investigator wishes. The use of artificial substrates also allows the investigator to study invertebrate colonization during time periods of interest to the researcher, i.e. the investigator is not limited to times (such as low flow) when natural substrates are available.

Artificial substrates can closely approximate natural substrates, such as rock-filled trays placed within rocky areas of a stream, or may be "standardized artificial substrates" that are dissimilar from natural substrates (Rosenberg and Resh 1982). Two of the most commonly used standardized artificial substrates are multiplate samplers constructed from masonite and rock-filled barbecue-basket samplers. Although the multiplate and basket samplers may be placed on the stream bottom, they are usually suspended in the water column where they are colonized by drifting invertebrates. Multiplate samplers have been used extensively for assessing water quality by researchers who use their invertebrate colonizers as biomonitors (US Environmental Protection Agency 1973, Simpson and Bode 1980, Beckett and Keyes 1983). Further information regarding the use of artificial substrates is available in US Environmental Protection Agency (1973), Flannagan and Rosenberg (1982), and Rosenberg and Resh (1982).

Freshwater invertebrates are usually preserved in 70-percent ethyl alcohol or a 5- to 10-percent formaldehyde solution. Although ethyl alcohol is preferred, formaldehyde is useful in field situations in which a large number of samples need to be preserved and it is not convenient or possible to transport a large amount of preservative. The addition of a small amount of rose bengal solution to the sample after preservation with formalin stains the invertebrates a bright red color and aids a great deal in the separation of the invertebrates from particles of sediment, plant materials, or detritus (Mason and Yevich 1967).

References

Aartila, T. P. 1988. "Psammophilic Invertebrates of the Lower Mississippi River: Community Composition and Densities in a Very Large Lotic System," M.S. thesis, University of Southern Mississippi, Hattiesburg, MS.

Arms, K., and Camp, P. S. 1987. Biology, 3d ed., Saunders College Publishing, Philadelphia, PA.

Barth, R. H., and Broshears, R. E. 1982. The Invertebrate World, Saunders College Publishing, Philadelphia, PA.

Barton, D. R., and Smith, S. M. 1984. "Insects of Extremely Small and Extremely Large Aquatic Habitats," The Ecology of Aquatic Insects, V. H. Resh and D. M. Rosenberg, eds., Praeger Publishers, New York.

Beckett, D. C. and Keyes, J. L. 1983. "A Biological Appraisal of Water Quality in the Ohio River Using Macroinvertebrate Communities, with Special Emphasis on the Chironomidae," Memoirs of the American Entomological Society 34:15-33.

Bingham, C. R., Mathis, D. B., Sanders, L. G., and McLemore, E. 1982. "Grab Samplers for Benthic Macroinvertebrates in the Lower Mississippi River," Miscellaneous Paper E-82-3, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Brundin, L. 1958. "The Bottom Faunistical Lake Type System and Its Application to the Southern Hemisphere; Moreover a Theory of Glacial Erosion as a Factor of Productivity in Lakes and Oceans," Internationale Vereinigung fur Theoretische und Angewandte Limnologie Verhandlungen 13:288-297.

Burks, B. D. 1953. "The Mayflies, or Ephemeroptera, of Illinois," Bulletin of the Illinois Natural History Survey 26:1-216.

Cairns, J., Jr., ed. 1982. Artificial Substrates, Ann Arbor Science Publishers, Ann Arbor, MI.

Coffman, W. P., and Ferrington, L. C., Jr. 1984. "Chironomidae," An Introduction to the Aquatic Insects of North America, R. W. Merritt and K. W. Cummins, eds., Kendall/Hunt Publishing Company, Dubuque, IA, pp 551-652.

Cummins, K. W., and Merritt, R. W. 1984. "Ecology and Distribution of Aquatic Insects," An Introduction to the Aquatic Insects of North America, R. W. Merritt and K. W. Cummins, eds., Kendall/Hunt Publishing Company, Dubuque, IA, pp 59-65.

Daly, H. V. 1984. "General Classification and Key to the Orders of Aquatic and Semiaquatic Insects," An Introduction to the Aquatic Insects of North America, R. W. Merritt and K. W. Cummins, eds., Kendall/Hunt Publishing Company, Dubuque, IA, pp 76-81.

Fisher, J. B. 1982. "Effects of Macrobenthos on the Chemical Diagenesis of Freshwater Sediments," Animal-Sediment Relations, The Biogenic Alteration of Sediments, P. L. McCall and M. J. S. Tevesz, eds., Plenum Press, New York, pp 177-218.

Flannagan, J. F., and Rosenberg, D. M. 1982. "Types of Artificial Substrates Used for Sampling Freshwater Benthic Macroinvertebrates," Artificial Substrates, J. Cairns, Jr., ed., Ann Arbor Science Publishers, Ann Arbor, MI, pp 237-266.

Fremling, C. O. 1960. "Biology and Possible Control of Nuisance Caddisflies of the Upper Mississippi River," Iowa State University Agricultural and Home Economics Experiment Station Research Bulletin 483:856-879.

Greeson, P. E., Ehlke, T. A., Irwin, G. A., Lium, B. W., and Slack, K. V., eds. 1977. "Methods for Collection and Analysis of Aquatic Biological and Microbiological Samples," Techniques of Water-Resources Investigations of the United States Geological Survey, US Government Printing Office, Washington, DC.

Hynes, H. B. N. 1984a. "The Relationships Between the Taxonomy and Ecology of Aquatic Insects," The Ecology of Aquatic Insects, V. H. Resh and D. M. Rosenberg, eds., Praeger Publishers, New York, pp 9-23.

Hynes, H. B. N. 1984b. "Aquatic Insects and Mankind," The Ecology of Aquatic Insects, V. H. Resh and D. M. Rosenberg, eds., Praeger Publishers, New York, pp 578-588.

Krull, J. N. 1970. "Aquatic Plant-Macroinvertebrate Associations and Waterfowl," Journal of Wildlife Management 34:707-718.

Lagler, K. F., Bardach, J. E., Miller, R. R., and Passino, D. R. M. 1977. Ichthyology, 2d ed., John Wiley and Sons, New York.

Laird, M., Aubin, A., Belton, P., Chance, M. M., Freeden, F. J. H., Haufe, W. O., Hynes, H. B. N., Lewis, D. J., Lindsay, I. S., McLean, D. M., Surgeoner, G. A., Wood, D. M., and Sutton, M. D. 1982. "Biting Flies in Canada: Health Effects and Economic Consequences," National Research Council of Canada, Publication No. 19248, Ottawa.

Lamberti, G. A., and Moore, J. W. 1984. "Aquatic Insects as Primary Consumers," The Ecology of Aquatic Insects, V. H. Resh and D. M. Rosenberg, eds., Praeger Publishers, New York, pp 164-195.

Lodge, D. M., Beckel, A. L., and Magnuson, J. J. 1985. "Lake-bottom Tyrant," Natural History 94:32-37.

Mason, W. T., Jr., and Yevich, P. P. 1967. "The Use of Phloxine B and Rose Bengal Stains to Facilitate Sorting Benthic Samples," Transactions of the American Microscopical Society 86:221-223.

Payne, B. S., and Miller, A. C. 1988. "Growth and Survival of Recent Recruits to a Population of *Fusconia ebena* (Bivalvia: Unionidae) in the Lower Ohio River," American Midland Naturalist 121:99-104.

Pennak, R. W. 1978. Fresh-water Invertebrates of the United States, 2d ed., John Wiley and Sons, New York.

Pflieger, W. L. 1975. The Fishes of Missouri, Missouri Department of Conservation, Columbia, MO.

Rosenberg, D. M., and Resh, V. H. 1982. "The Use of Artificial Substrates in the Study of Freshwater Benthic Macroinvertebrates," Artificial Substrates, J. Cairns, Jr., ed., Ann Arbor Science Publishers, Ann Arbor, MI, pp 175-325.

Rzoska, J., ed. 1976. "The Nile, Biology of an Ancient River," Monographiae Biologicae, Vol 29, Dr. W. Junk Publishers, The Hague, The Netherlands.

Saether, O. A. 1975. "Nearctic Chironomids as Indicators of Lake Typology," Internationale Vereinigung fur Theoretische und Angewandte Limnologie Verhandlungen 19:3127-3133.

Simpson, K. W., and Bode, R. W. 1980. "Common Larvae of Chironomidae (Diptera) from New York State Streams and Rivers," New York State Museum Bulletin 439:1-105.

Swanson, G. A., Meyer, M. I., and Serie, J. R. 1974. "Feeding Ecology of Blue-winged Teals," Journal of Wildlife Management 38:396-407.

US Environmental Protection Agency. 1973. "Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents," Cincinnati, OH.

LARVAL FISH INVESTIGATIONS

William D. Pearson*

Introduction

Fish eggs and larvae are of special interest to fishery biologists because the subsequent strength of a given year class of fishes is often established or set in the first few weeks of life (Hjort 1926). Some investigators have identified a "critical period," when the larval fish changes from endogenous food supplies to exogenous foods, as the time when the year class strength is established (May 1974). Recently, some marine fishery biologists have emphasized the importance of physical environmental conditions (temperature and currents) as determinants of larval survival (Cushing 1975, Bailey and Francis 1985).

A review of the life cycle of fishes in large rivers indicates that there are three weak links where the general size and productivity of a given fish population might be limited. These occur with (1) the point of energy transfer from the usually abundant allochthonous energy inputs of terrestrial vegetation to the food organisms consumed by larval fishes, (2) the operation of mortality sources other than starvation on larval fishes, and (3) the availability of suitable spawning substrate (Figure 1). Cooling water withdrawals, pollution, and the installation and operation of both hydroelectric and navigation dams can all increase mortality rates of larval fishes. The installation of dams can result in the inundation and/or sedimentation of the coarse spawning substrates preferred by many riverine fishes.

When one compares the fish communities of the inland waterways of North America today with those reported before 1920, it appears that very few species have been lost, a few exotics have been introduced, and the relative abundance of species has shifted. Members of the lithophil guilds that spawn over coarse gravel substrates have decreased, while members of the pelagic guilds that produce floating eggs and/or larvae have increased (Pearson and Krumholz 1984). Comparative data on riverine fish population densities through time are scarce and difficult to interpret. Still, it appears that

* Water Resources Laboratory, University of Louisville, Louisville, KY.

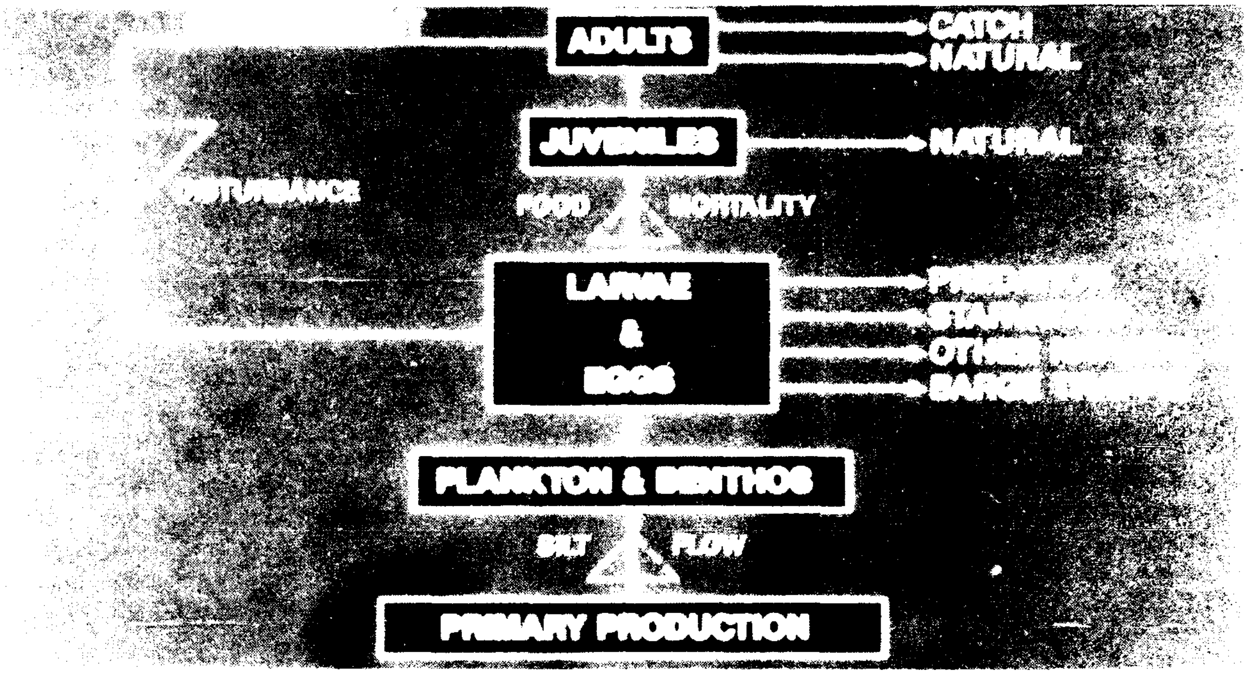


Figure 1. Life history model [illegible] river fishes.

[illegible] riverine fish populations are rather robust in their ability to [illegible] [illegible] increased mortalities associated with human perturbations through density dependent increases in growth and reproduction (Dahlberg [illegible]; [illegible] & [illegible], [illegible]).

Sampling Larval Fishes and Fish Eggs

Fishes in the [illegible] waters of [illegible] America generally spawn in the [illegible] April–July, although some (e.g., northern pike) spawn earlier and some (e.g., bluegill) spawn over a long period that may extend into the fall. In [illegible] large rivers, the peak of spawning may be expected in May and June. In establishing a sampling schedule and locating sampling stations, one must consider the spawning habits and habitats of the target species, their [illegible] [illegible] responses (which may change dramatically with developmental stage), and the objectives of the study, including the subsequent operations to be performed on the specimens (e.g., food habits analysis, otolith preparation for [illegible], and morphometrics).

Actively towed or pushed nets are the most popular methods for collecting larval fishes and fish eggs. Nets may be fished at either low [illegible] or high (>2 m/sec) speeds. Low-speed nets include 0.25- to 1-m-diam plankton nets, bongo nets, and Tucker trawls (Snyder 1983). High-speed nets include the Miller and Gulf III samplers. Mesh sizes are typically 0.3 to 1.0 mm. Many problems arise from the change in filtering efficiency experienced as the mesh clogs with debris, the extrusion of larvae through the mesh, net avoidance associated with larval detection of the towing bridle, and quantification of the metered sample.

For special purposes, or for deployment in unusual habitats, other gear types may be preferred. Small hand-pulled seines, miniature purse seines, trash pumps, substrate samplers, and drift nets can be employed. Miniature maze-type traps have been used, sometimes in combination with an internal light source to attract larvae at night.

Identification of Larval Fish

Larval fishes do not offer the variety and constancy of identifying morphological characters seen in adult fishes. In the early stages of larval development, fin rays, spines, and scales are lacking, and body proportions are usually very different from those of the adult. A binocular dissecting microscope of good quality, equipped with an eyepiece micrometer and a polarizing light attachment, is essential for examination of larval fish. The micrometer allows for accurate measurements of structures and body segments; the polarized light attachment makes it easier to distinguish myomeres and incipient fin rays and spines. A set of miniature dissecting tools constructed from insect pins and carbon steel razor blade fragments, together with fine insect forceps and pipettes, will be useful in manipulating the specimens.

Characters that are particularly useful in identifying riverine fish larvae include the location of the anus (often expressed as the preanal to postanal length percentage); myomere counts (also both preanal and postanal counts); eye diameter; morphology of the gut; presence, shape, and location of yolk-sac; morphology of the air bladder; length at a particular developmental stage; and pigmentation patterns (Figure 2).

Regional keys and guides to freshwater fish eggs and larvae that are particularly useful for identifying riverine species have been listed by Simon (1986) and include Auer (1982), Hardy et al. (1978), and Hogue, Wallus, and Kay (1976).

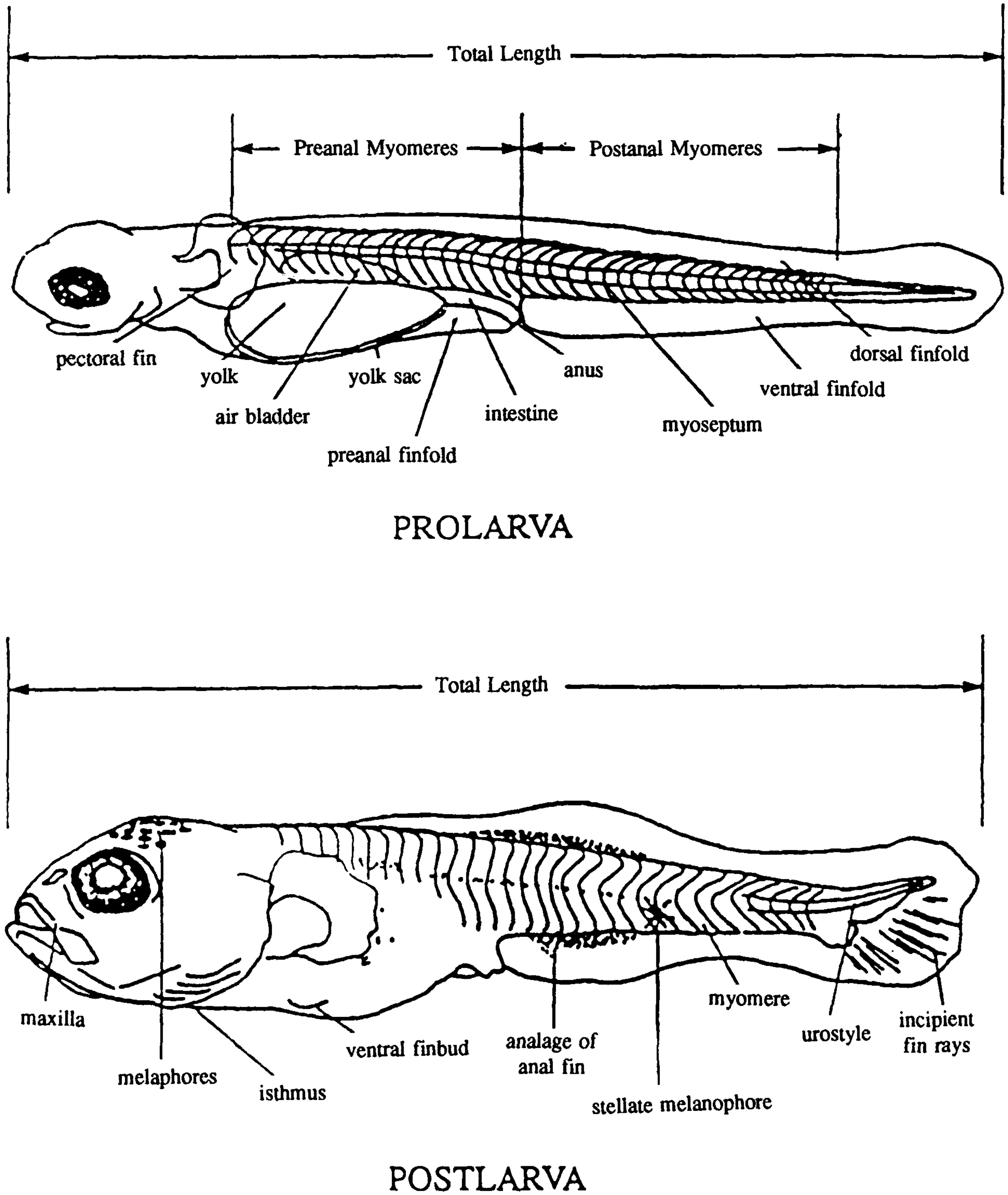


Figure 2. Typical prolarval and postlarval fishes (after McGowen 1988)

Suggested Future Studies

The food habits of larval fishes are of interest as a means of directly determining the effects of diet on year class strength. The dissection of larval stomachs under the binocular microscope is tedious, but rather quickly accomplished since the number of food items per fish is usually low.

Condition indices calculated from measurements of body segments can also be used as indicators of the dietary history of the fish, and for relating feeding success to survival and year class strength. The application of digitizing pads and measurement programs can improve both the speed and accuracy of data gathering.

The otoliths of larval fish can be examined, and daily growth rates can be determined. The recent development of these techniques makes it possible to examine the effects of short-term events on the growth rates of larval fish of specific ages. For example, it is now possible to select a river segment during the spawning season of a particular species and examine the effects of any perturbation (natural, human-caused, or experimental) on the growth rates of fish during the first few days after hatching. These rates could then be compared to the growth rates of fishes hatched just before and/or after the perturbation.

These and other promising lines of investigation will be pursued by fisheries biologists interested in determining the effects of environmental alterations on the production of riverine fishes through the end of this century.

Annotated List of Publications Concerning the Collection, Identification and Interpretation of Larval Fish Samples

General references

Early Life History (ELH) Section Newsletter. American Fisheries Society (AFS), Bethesda, MD. This quarterly newsletter by the ELH section of the AFS provides the latest information on meetings, publications, and research activities of the approximately 400 members.

Hoyt, R. D. 1988. A bibliography of the early life history of fishes. Vols I & II. Western Kentucky University, Bowling Green, KY. This two volume set provides a comprehensive list of publications (13,700!) concerning the early life history of fishes. It has subject, scientific name, common name, family name, and location indexes. This is the place to start on any literature review concerning larval fish and eggs. The location index is a particularly novel and useful tool for those planning a study of unfamiliar waters. At $50, this set is a bargain.

Snyder, D. E. 1983. Fish eggs and larvae. Pages 165-197 *in* L. A. Nielsen and D. L. Johnson, eds., Fisheries Techniques. American Fish. Soc., Bethesda, MD. This chapter in the well-known text published by AFS provides the best concise review of all subjects concerning fish eggs and larvae available to date. It covers sampling methods, sample handling and preservation techniques, the bases of identification of larvae, and egg counts. This is the first item to read for fisheries biologists without previous larval fish experience.

Larval Fish Conference Proceedings. This conference has been held each year since 1977 (the 13th was held in May 1989 in Mexico). The ELH section of AFS has sponsored the recent meetings. The collections of papers published in the conference proceedings cover all aspects of larval fish investigations. The publisher varies, although the AFS has published most of the recent volumes.

Collection and field techniques

Gregory, R. S., and Powles, P. M. 1988. Relative selectivities, Miller high-speed samplers and light traps for collecting ichthyoplankton. Can. J. Fish. Aquat. Sci. 45:993-998. This paper compares two sampling gears and discusses the limitations of both. The literature review section leads one into the older literature concerning sampling methods and problems.

Snyder, D. E. 1983. Cited in the previous section, this chapter illustrates most of the common gear types and discusses their relative merits.

Identification manuals and keys

Auer, N. A., ed. 1982. Identification of larval fishes of the Great Lakes Basin with emphasis on the Lake Michigan drainage. Great Lakes Fish. Comm. Spec. Publ. 82-3, Ann Arbor, MI. 744 pp. This large work provides keys to and illustrations of larvae of the most common fishes of the Great Lakes area.

Hardy, J. D., Jr., Drewry, G. E., Fritzsche, R. A., Johnson, G. D., Jones, P. W., and Martin, F. D. 1978. Development of fishes of the Mid-Atlantic Bight, an atlas of egg, larval and juvenile stages. Vols I-VI. FWS/OBS-78/12, US Fish and Wildlife Serv., Washington, DC. This six volume set provides no keys, but does have good illustrations of many of the most common freshwater and estuarine fishes of the East Coast. It is a reference set for the eastern lab beginning larval fish investigations.

Hogue, J. J., Wallus, R., and Kay, L. K. 1976. Preliminary guide to the identification of larval fishes in the Tennessee River. Tenn. Vall. Auth., Tech. Note B19, Norris, TN. This work contains the best simplified key to freshwater fish families of the eastern United States. If you are beginning to identify larval fishes of the Mississippi drainage, this is the key to begin with. Although it is getting somewhat "long in the tooth," it is still probably available from TVA.

Simon, T. P. 1986. A listing of regional guides, keys, and comparative descriptions of freshwater and marine larval fishes. American Fish. Soc., Early Life History Section Newsletter 7(1):10-15. This is an excellent list of the keys available for North American larval fishes. The title reflects the fragmented nature of the literature concerning this very recently evolved branch of fisheries. There is no overall key to the larval fishes of the United States or North America. For definitive identifications it is necessary to consult a variety of regional "guides," species lists for adult fishes in the body of water under consideration, and "comparative descriptions" of closely related species.

Interpretation of results

The following brief list provides examples of how larval fish data can be used to infer effects on adult fish stocks. Most of this experience has been gained in assessments of the effects of power plant cooling water withdrawals on fish populations.

Barnthouse, L. W., Klauda, R. J., Vaughan, D. S., and Kendall, R. L., eds. 1988. Science, law, and Hudson River power plants: A case study in environmental impact assessment. American Fish. Soc. Monograph 4. Bethesda, MD. This is a collection of papers covering the field sampling methods, biology of larval fishes, modeling of population dynamics, etc., used in the Hudson River power plant impact and litigation controversy.

Dahlberg, M. D. 1979. A review of survival rates of fish eggs and larvae in relation to impact assessments. Mar. Fish. Rev. 41(3):1-12. A good overall review of the subject of compensation in fish populations, and the value of ELH studies.

McFadden, J. T. 1977. An argument supporting the reality of compensation in fish populations and a plea to let them exercise it. Pages 153-183 in W. Van Winkle, ed. Proceedings of the conference on assessing the effects of power plant-induced mortality of fish populations. Pergamon Press, New York, NY. 380 pp. Another discussion on compensation in a good volume on the effects of power plants on fish populations.

Merriman, D., and Thorpe, L. M. 1976. The Connecticut River ecological study: The impact of a nuclear power plant. Amer. Fish. Soc. Monograph 1. Bethesda, MD. A comprehensive case study of the effects of a power plant on fish populations in a river, acting primarily on larval fishes. The effects of density-independent regulating mechanisms are given emphasis in several of the papers.

R. G. Otto & Assoc. 1987. Compensatory mechanisms in fish populations: An EPRI research plan. Electric Power Research Institute, Palo Alto, CA. A review of compensatory mortality in fishes and suggested lines of future research.

Additional citations

Bailey, K. M., and Francis, C. R. 1985. "Recruitment of Pacific Whiting, *Merluccius productus*, and the Ocean Environment," Mar. Fish. Rev. 47(2):8-15.

Cushing, D. H. 1975. Marine Ecology and Fisheries. Cambridge Univ. Press, Cambridge, MA.

Hjort, J. 1926. "Fluctuations in the Year Classes of Important Food Fishes," J. Cons. Int. Explor. Mer. 1:5-38.

May, R. C. 1974. "Larval Mortality in Marine Fishes and the Critical Period Concept," The Early Life History of Fish. J. H. S. Blaxter, ed., Springer-Verlag, New York, pp 3-19.

McGowen, E. G. 1988. "An Illustrated Guide to Larval Fishes from Three North Carolina Piedmont Impoundments," Carolina Power and Light Company, New Hill, NC.

Pearson, W. D., and Krumholz, L. A. 1984. "Distribution and Status of Ohio River Fishes," ORNL/SUB/79-7831/1, Oak Ridge National Laboratory, Oak Ridge, TN.

TECHNIQUES USED IN FISHERY EVALUATION STUDIES

K. Jack Killgore*

Introduction

Three broad categories of assessment techniques are used to evaluate the effects of habitat alteration on fishes: habitat-based, species/population, and community level. Selection of a method usually depends on study objectives, proposed operations of the project, and status of the existing fishery. A combination of techniques is often used to adequately assess temporal distribution and abundance of fishes in the various habitats of the study area.

This paper summarizes selected sampling techniques and assessment methods previously used in Corps fishery studies of water resource projects, with emphasis on warmwater stream fishes. Classification of fishes and their habitat is addressed first, followed by an overview of habitat-based techniques, including sampling methods to identify habitat utilization and preference by fishes. This is followed by a discussion on the relevance of population- and community-level data to habitat-based techniques.

Habitat Classification of Fishes

Selection of target species is an important task in the environmental assessment of water resource projects. Target species are frequently selected according to their commercial and ecological value, habitat requirements, and susceptibility to project impacts. However, the selection process can be complicated in water bodies with high species richness, such as warmwater rivers. In these cases, classification of fishes into guilds can simplify the selection process, as well as provide a community-level evaluation framework (Leonard and Orth 1988). A guild is a group of species that exploit the same class of environmental resources in a similar way (Root 1967), and therefore members of a guild should be affected similarly by the alteration of those resources (Roberts and O'Neil 1985). Fish communities can be partitioned according to several types of criteria, including feeding preferences

---

* US Army Engineer Waterways Experiment Station, Vicksburg, MS.

(piscivore, insectivore, omnivore), reproductive strategies (nest builders, pelagic spawners), and habitat selection (slackwater, swiftwater). However, in Corps fishery studies, habitat is generally emphasized because alteration of physical features through channelization, levee construction, and navigation improvements (revetment, dikes) directly affects the quality of the aquatic environment.

The habitats of many floodplain rivers often align into six groups: main stem swift-current; main stem slackwater; larger, permanent floodplain; seasonally inundated floodplain; swamp ponds; and tributary mouths (Baker, Killgore, and Kasul 1989). Main stem swift-current habitats include channel, natural steep bank, revetted bank, and lotic sandbar; main stem slackwater habitats are the lentic sandbar and pool. Sloughs, oxbow lakes, and borrow pits are permanently inundated floodplain habitats; these may become connected to the river at higher stages by overbank flows onto the seasonally inundated floodplain. Swamp pond habitat consists of permanent but relatively small, shallow, isolated water bodies located in alluvial river swamps. Tributary mouths range from slow to swiftly flowing depending on the tributary and season of year.

Each of these habitats can be classified by physical attributes including depth, current, substrate, potential for instream structure (snags and inundated vegetation), degree of annual inundation, and permanence of connection to the Mississippi river channel. These variables have been identified as important in structuring fish communities in a variety of stream ecosystems (Barnickol and Starrett 1951, Gorman and Karr 1978, Becker 1983, Leonard and Orth 1988, Ross 1986). Depending on the objectives of the environment assessment, target species can be selected either from a group of habitats (e.g., main stem slackwater) or a specific habitat (e.g., lotic sandbar) to represent other members of the guild.

An example of a habitat classification for large riverine fishes is shown in Table 1 (page 80). Water velocity is a major habitat axis along which fish species segregate in riverine environments (Leonard and Orth 1988; Baker, Killgore, and Kasul 1989). Therefore, fish species were classified as either slackwater or swiftwater inhabitants. Guilds are based on the premise that tolerance to habitat changes varies with size of the species, while some species use a wide range of conditions (generalists). These criteria result in the formation of five guilds: swiftwater-large fishes (Group 1), swiftwater-small fishes (Group 2), slackwater-large fishes (Group 3), slackwater-small fishes (Group 4), and generalists (Group 5). Although there are exceptions, most members of a guild share important morphological similarities (e.g., fusiform shape for swiftwater fishes and laterally compressed shape for slackwater fishes) and exhibit the same ontogenetic shifts in preferred habitat (e.g., shallow vegetated areas to open water).

If habitat guilds are to be of value in describing present conditions, or predicting future biological changes given hypothetical physical changes, the habitats identified must conform to those recognized by the organisms. For example, rivers comprise a mosaic of changing features such as current, substrate, depth, debris (cover), and water chemistry (Hutchinson 1957, Platts 1979, Osgood and Barber 1982). Some features change gradually and may stay relatively constant over large areas; other features change abruptly and frequently on a relatively small scale. All features can change dramatically over relatively short periods of time as river stage rises or falls. Classification is an attempt to divide features into a few useful and manageable categories. In a complex and constantly changing environment, classifications tend to oversimplify the biological importance of aquatic habitats. For this reason, several schemes have been proposed to fill different information needs; no one classification has proven to be best for all situations.

Habitat-Based Assessment Techniques

Because habitat-based techniques are more consistent with time and money available, emphasis has been placed on defining suitable habitat conditions that can support a viable fishery. Habitat-based techniques generally assume that habitat quality can be used to rate the biological importance of project areas to fishes. An index of habitat quality is often part of the evaluation process, and various methods are used to prepare these indices. An example is Suitability Index (SI) curves used in the Habitat Evaluation Procedures (HEP) and the Instream Flow Incremental Methodology (IFIM).

A variety of techniques have evolved to prepare SI curves (Table 2). The use of indirect techniques to establish habitat preferences, such as mobile electroshocking devices, fixed electrodes, nets, and radiotelemetry, is generally limited to nonspawning adults and juveniles. If environmental conditions are adequate, underwater and bank observation can be used to locate the position and type of activity (resting, feeding, spawning) of fishes relative to specific physical and water quality variables. Other techniques include the Delphi Method and the use of controlled laboratory environments. In difficult to sample environmental conditions (deep, fast-flowing water, high turbidity), indirect observation of fish through the use of a calibrated hydroacoustic system may be required (Kasul et al. 1988). Other techniques such as popnets (Figure 1) and larval light traps (Figure 2) are useful to sample fishes in complex habitats such as aquatic plants.

Spawning criteria are particularly difficult to determine because spawning is a specific short-duration activity (Bovee 1986). However, if a fish's spawning habitat can be created in the laboratory, then direct observation of its behavior can improve our understanding of spawning requirements. One type of spawning strategy conducive to laboratory observation is known as crevice spawning. For example, a controlled laboratory setting (Figure 3) has been used to examine the effect of current on spawning preference by the blacktail shiner (Killgore, Baker, and Miller 1988). This species is a crevice spawner ubiquitous throughout the southeastern United States and is the dominant shiner in many warmwater streams (Pflieger 1975). The results of this study indicated that the blacktail shiner will not spawn in zero velocity and avoids the higher range of velocities. This type of approach can provide the opportunity to develop SI curves for specific habitat requirements that were previously based on circumstantial evidence, consensus of opinion, or review of the literature.

Relationship of Population- and Community-Level Studies to Habitat-Based Evaluations

Simultaneous measurements of physicochemical habitat variables and fish population parameters (e.g., standing crop, recruitment, growth rates) can reveal important relationships between fishes and their environment. Most habitat-based techniques assume a relationship between habitat quality and "carrying capacity" (EPRI 1986). Relating habitat quality indices to some biological response variable such as standing crop is an important step in recognizing the validity of the results. Analysis of this type of data can also include community-level interactions such as competition and predation. Numerous resource partitioning indices (e.g., overlap, breadth, diversity) can assist in interpreting community interactions (Ludwig and Reynolds 1988). A relatively new approach, the Index of Biotic Integrity (IBI), is also used in a variety of ecosystems to document the importance of fish assemblages. An

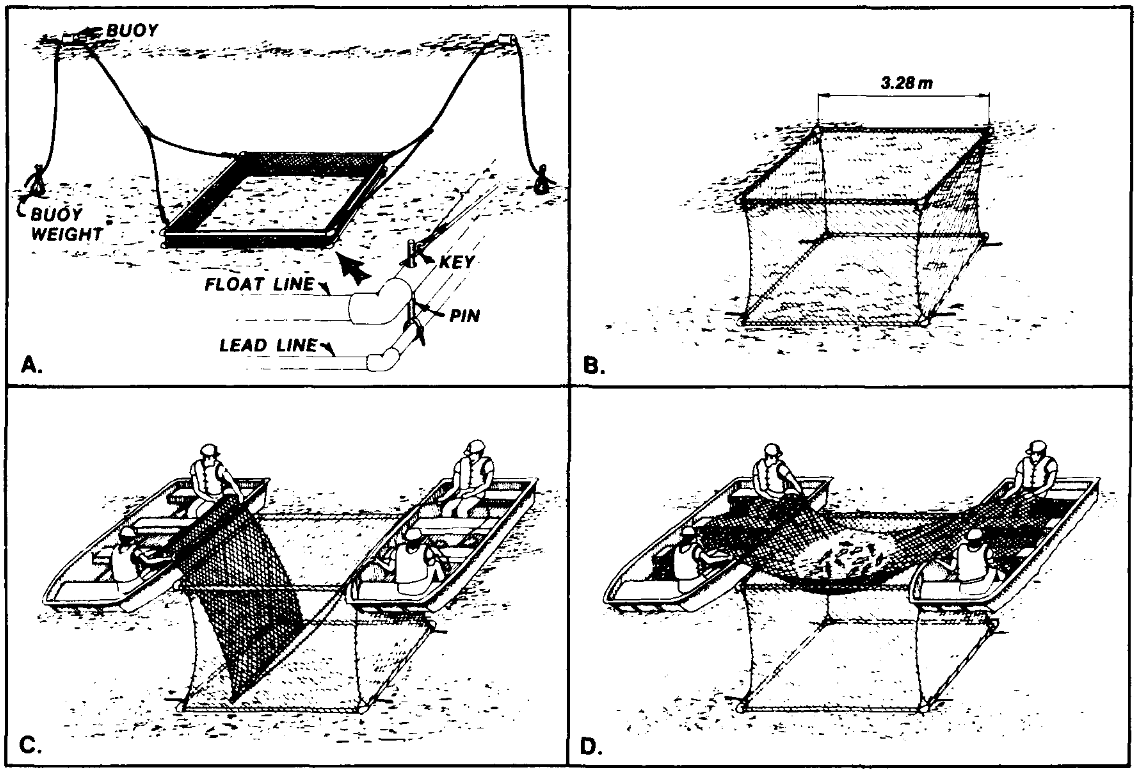


Figure 1. Schematic diagram of popnet system and the setup for fishing the net

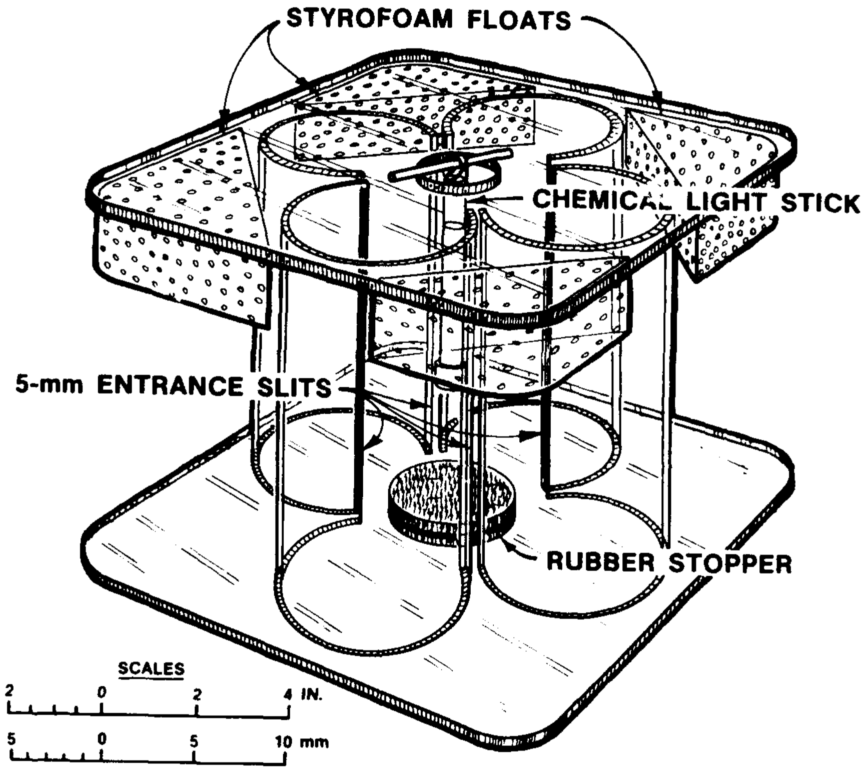


Figure 2. Schematic of a larval light trap using chemical light sticks

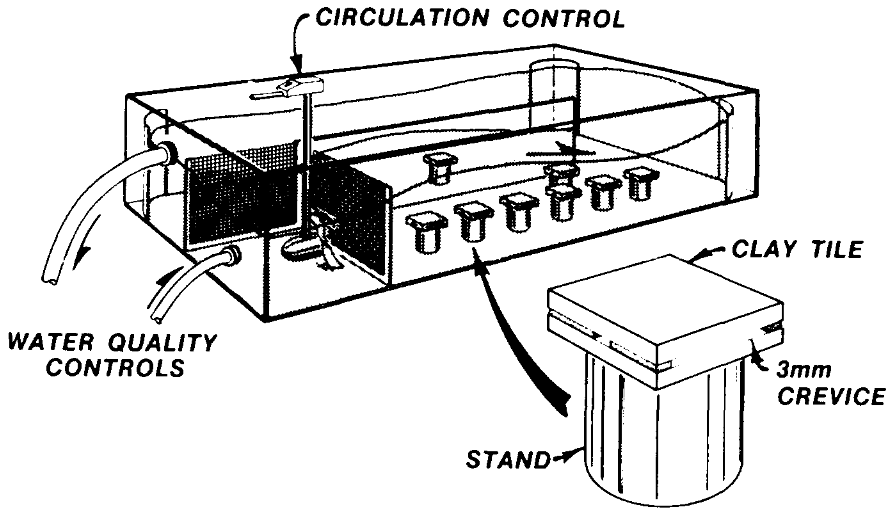


Figure 3. Schematic of a water velocity flume and artificial crevices used by spawning blacktail shiners (*Notropis venustus*)

example of IBI metrics developed for rivers in northeast Louisiana (Killgore and Douglas 1988) is shown as Table 3. The combination of metrics is designed to reflect insights from individual, population, community, ecosystem, and zoogeography perspectives (Miller et al. 1988).

Long-term monitoring of fish populations may be the only approach to better understand the influences of man-made and natural perturbations on ecosystem process. Results of long-term studies can help identify trends and major shifts in population structure, establish natural limits of variation, identify potential cause-and-effect mechanisms through correlation, and provide a basis for more meaningful short-term studies. If these studies incorporate at least one generation time of the species of interest and are conducted over the range of habitat conditions that will potentially occur during the life of the water resource project, the phys_cal and biological factors that influence fishes will be better understood.

References

Baker, J. A., Killgore, K. J., and Kasul, R. L. 1989. "Aquatic Habitats and Fish Communities in the Lower Mississippi River," Critical Reviews in Aquatic Sciences (in press).

Barnickol, P. G., and Starrett, W. C. 1951. "Commercial and Sport Fishes of the Mississippi River Between Caruthersville, Missouri and Dubuque, Iowa," Illinois Natural History Survey Bulletin 25.

Becker, G. C. 1983. Fishes of Wisconsin. The University of Wisconsin Press, Madison, WI.

Bovee, K. D. 1986. "Development and Evaluation of Habitat Suitability Criteria for Use in the Instream Flow Incremental Methodology," Instream Flow Information Paper 21, US Fish and Wildlife Service Biological Report 86(7), Washington, DC.

Crance, J. H. 1987. "Habitat Suitability Index Curves for Paddlefish Developed by the Delphi Technique," North American Journal of Fisheries Management 7:123-130.

Cunjak, R. A., and Power, G. 1986. "Winter Habitat Utilization by Stream Resident Brook Trout (*Salvelinus fontinalis*) and Brown Trout (*Salmo trutta*)," Canadian Journal of Fisheries and Aquatic Sciences 43:1970-1981.

DeGraff, D. A., and Bain, L. H. 1986. "Habitat Use by and Preferences of Juvenile Atlantic Salmon in Two Newfoundland Rivers," Transactions of the American Fisheries Society 115:671-681.

EPRI. 1986. "Instream Flow Methodologies," Electric Power Research Institute, Palo Alto, CA.

Gorman, O. T., and Karr, J. R. 1978. "Habitat Structure and Stream Fish Communities," Ecology 59:507-515.

Greenberg, L. A., and Holtzman, D. A. 1987. "Microhabitat Utilization, Feeding Periodicity, Home Range and Population Size of the Banded Sculpin, *Cottus carolinae*, Copeia 1987(1):19-25.

Hutchinson, G. E. 1957. A Treatise on Limnology. Vol 1, John Wiley and Sons, New York.

Jones, R. N., Orth, D. J., and Maughan, O. E. 1984. "Abundance and Preferred Habitat of the Leopard Darter, *Percina pantherina*, in Glover Creek, Oklahoma," Copeia 1984(2):378-384.

Kasul, R. L., Miller, A. C., Killgore, K. J., and Coleman, R. E. 1988. "Habitat Suitability Measurements for Fish Communities Models Using Hydroacoustics," in "Habitat Evaluation Methods Notebook," Instruction Report EL-85-3, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Killgore, K. J., and Douglas, N. H. 1988. "Effects of Surface Water Withdrawal on Fishes in Rivers of Northeast Louisiana," Technical Report EL-88-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Killgore, K. J., Baker, J. A., and Miller, A. C. 1988. "A Method to Determine Suitability Index Criteria for Spawning Fishes," in "Habitat Evaluation Methods Notebook," Instruction Report EL-85-3, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Larimore, R. W., and Garrels, D. D. 1985. "Assessing Habitats Used by Warmwater Stream Fishes," Fisheries 10(2):10-16.

Leonard, P. M., and Orth, D. J. 1988. "Use of Habitat Guilds of Fishes to Determine Instream Flow Requirements," North American Journal of Fisheries Management 8:399-409.

Ludwig, J. A., and Reynolds, J. F. 1988. Statistical Ecology. John Wiley and Sons, New York.

Miller, D. E., et al. 1988. "Regional Applications of an Index of Biotic Integrity for Use in Water Resource Management," Fisheries 13(5):12-20.

Morantz, D. L., Sweeney, R. K., Shirvell, C. S., and Longard, D. A. 1987. "Selection of Microhabitat in Summer by Juvenile Atlantic Salmon (*Salmon salar*)," Canadian Journal of Fisheries and Aquatic Sciences 44:120-129.

Moyle, P. B., and Baltz, D. M. 1985. "Microhabitat Use by an Assemblage of California Stream Fishes: Developing Criteria for Instream Flow Determinations," Transactions of the American Fisheries Society 114:695-704.

Moyle, P. B., and Vondracek, B. 1985. "Persistence and Structure of the Fish Assemblage in a Small California Stream," Ecology 66(1):1-13.

Orth, D. J., and Maughan, E. O. 1982. "Evaluation of the Incremental Methodology for Recommending Instream Flows for Fishes," Transactions of the American Fisheries Society 111:413-445.

Oswood, M. E., and Barber, W. E. 1982. "Assessment of Fish Habitat in Streams: Goals, Constraints, and a New Technique," Fisheries 7(3).

Pflieger, W. L. 1975. The Fishes of Missouri, Missouri Department of Conservation, Columbia, MO.

Platts, W. S. 1979. "Relationships Among Stream Order, Fish Populations, and Aquatic Geomorphology in an Idaho River Drainage," Fisheries 4(2).

Rankin, E. T. 1986. "Habitat Selection by Smallmouth Bass in Response to Physical Characteristics in a Natural Stream," Transactions of the American Fisheries Society 115:322-334.

Roberts, T. H., and O'Neil, L. J. 1985. "Species Selection for Habitat Assessments," Miscellaneous Paper EL-85-8, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Root, R. B. 1967. "The Niche Exploitation Pattern of the Blue-Gray Gnatcatcher," Ecology 37:317-350.

Ross, S. T. 1986. "Resource Partitioning in Fish Assemblages: A Review of Field Studies," Copeia 352.

Sechnick, C. W., Carline, R. F., Stein, R. A., and Rankin, E. T. 1986. "Habitat Selection by Smallmouth Bass in Response to Physical Characteristics of a Simulated Stream," Transactions of the American Fisheries Society 115:314-321.

Sheppard, J. D., and Johnson, J. H. 1985. "Probability-of-Use for Depth, Velocity, and Substrate by Subyearling Coho Salmon and Steelhead in Lake Ontario Tributary Streams," North American Journal of Fisheries Management 5:277-282.

Shirvell, C. S., and Dungey, R. G. 1983. "Microhabitats Chosen by Brown Trout for Feeding and Spawning in Rivers," Transactions of the American Fisheries Society 112:355-367.

Southall, P. D., and Hubert, W. A. 1984. "Habitat Use by Adult Paddlefish in the Upper Mississippi River," Transactions of the American Fisheries Society 113:125-131.

Tyus, H. M., Burdick, B. D., and McAda, C. W. 1984. "Use of Radiotelemetry for Obtaining Habitat Preference Data on Colorado Squawfish," North American Journal of Fisheries Management 4:177-180.

Table 1

Habitat Classification of Selected Fishes Found in Large River Systems

Family and Species	Group*
Lepisosteidae	
Longnose gar (*L. osseus*)	5
Shortnose gar (*L. platostomus*)	5
Amiidae	
Bowfin (*Amia calva*)	3
Anguillidae	
American eel (*Anguilla rostrata*)	3
Clupeidae	
Skipjack herring (*Alosa chrysochloris*)	1
Gizzard shad (*Dorosoma cepedianum*)	5
Threadfin shad (*D. petenense*)	3
Hiodontidae	
Goldeye (*Hiodon alosoides*)	1
Mooneye (*H. tergisus*)	1
Esocidae	
Grass pickerel (*Esox americanus*)	3
Northern Pike (*E. lucius*)	3
Cyprinidae	
Common carp (*Cyprinus carpio*)	5
Goldfish (*Carassius auratus*)	5
Golden shiner (*Notemigonus crysocleucas*)	4
Suckermouth minnow (*Phenacobius mirabilis*)	2
Central stoneroller (*Campostoma anomalum*)	2
Silver chub (*Hybopsis storeriana*)	2
Emerald shiner (*N. atherinoides*)	5
River shiner (*N. blennius*)	2
Striped shiner (*N. chrysocephalus*)	2
Bigmouth shiner (*N. dorsalis*)	2
Ribbon shiner (*N. fumeus*)	4
Blacknose shiner (*N. heterolepis*)	2
Spottail shiner (*N. hudsonius*)	4
Red shiner (*N. lutrensis*)	5
Silverband shiner (*N. shumardi*)	2
Spotfin shiner (*N. spilopterus*)	2

(Continued)

* Groups are: 1, swiftwater, large fish; 2, swiftwater, small fish; 3, slackwater, large fish; 4, slackwater, small fish; and 5, generalist.

(Sheet 1 of 4)

Table 1 (Continued)

Family and Species	Group
Cyprinidae (Cont.)	
Redfin shiner (*N. umbratilis*)	2
Steelcolor shiner (*N. whipplei*)	2
Bullhead minnow (*Pimephales vigilax*)	5
Bluntnose minnow (*P. notatus*)	5
Fathead minnow (*P. promelas*)	5
Catostomidae	
River carpsucker (*Carpiodes carpio*)	5
Quillback (*C. cyprinus*)	3
Highfin carpsucker (*C. velifer*)	1
White sucker (*Catostomus commersoni*)	1
Smallmouth buffalo (*Ictiobus bubalus*)	3
Bigmouth buffalo (*I. cyprinellus*)	3
Black buffalo (*I. niger*)	3
Shorthead redhorse (*Moxostoma macrolepidotum*)	1
Silver redhorse (*M. anisurum*)	1
River redhorse (*M. carinatum*)	1
Golden redhorse (*M. erythrurum*)	1
Black redhorse (*M. duquesnei*)	1
Ictaluridae	
Black bullhead (*Ictalurus melas*)	5
Yellow bullhead (*I. natalis*)	5
Brown bullhead (*I. nebulosus*)	5
Channel catfish (*I. punctatus*)	3
Flathead catfish (*Pylodictis olivaris*)	3
Cyprinodontidae	
Starhead minnow (*Fundulus notti*)	4
Blackstripe topminnow (*F. notatus*)	4
Poeciliidae	
Mosquitofish (*Gambusia affinis*)	5
Atherinidae	
Brook silverside (*Labidesthes sicculus*)	4
Percichthyidae	
White bass (*Morone crysops*)	3
Yellow bass (*M. mississippiensis*)	3
Centrarchidae	
Rock bass (*Ambloplites rupestris*)	4
Green sunfish (*Lepomis cyanellus*)	5
Pumpkinseed (*L. gibbosus*)	4
Warmouth (*L. gulosus*)	4

(Continued)

(Sheet 2 of 4)

Table 1 (Continued)

Family and Species	Group
Centrarchidae (Cont.)	
Orangespotted sunfish (*L. humilis*)	5
Bluegill (*L. macrochirus*)	5
Longear sunfish (*L. megalotis*)	4
Redear sunfish (*L. microlophus*)	4
Largemouth bass (*Micropterus salmoides*)	3
Smallmouth bass (*M. dolomieui*)	1
White crappie (*Pomoxis annularis*)	3
Black crappie (*P. nigromaculatus*)	3
Percidae	
Logperch (*Percina caprodes*)	5
Blackside darter (*P. maculata*)	2
Sauger (*Stizostedion canadense*)	1
Walleye (*S. vitreum*)	1
Sciaenidae	
Freshwater drum (*Aplodinotus grunniens*)	5

DESCRIPTIONS

Group 1 - Swiftwater, Large Fishes

The 13 species in this group, most of which are rare to uncommon, are large, pelagic-oriented fish that prefer rather clear, fast-flowing water over a sand or gravel substrate. Most species are migratory, travel in schools, and often constitute an important commercial fishery. Spawning occurs over sand or gravel shoals in the spring. The fry of this group are usually pelagic and move into shallower water as they grow, feeding on plankton and small invertebrates. The adults feed on large invertebrates or fishes.

Group 2 - Swiftwater, Small Fishes

This group of 12 species is comprised of small minnows and darters that are important forage fishes; their presence generally indicates good riverine habitat. They often travel in schools and occupy similar habitat as described for species in Group 1, but generally occur in shallower water and do not migrate great distances. Reproduction behavior is variable, but spawning usually occurs during the spring over sand or gravel in flowing water. Their diet consists of plankton and small invertebrates.

Group 3 - Slackwater, Large Fishes

This group of 16 species inhabits slackwater areas and generally avoids strong current. Because of their large size and relative high abundance, many of these species are important commercial and recreational fish. They often

(Continued)

(Sheet 3 of 4)

Table 1 (Concluded)

Group 3 - Slackwater, Large Fishes (Cont.)

associate with vegetation, woody debris, or other forms of cover in deeper parts of pools, occasionally entering flowing water to feed. The majority of the species in this group are piscivorous as adults, except for the suckers and bullheads which feed on molluscs, insects, and plankton. Spawning occurs during the spring and early summer in shallow, nonflowing water over vegetation, logs, or prepared nests. One notable exception is the American eel, which spawns around the Sargasso Sea.

Group 4 - Slackwater, Small Fishes

This group of relatively small fish is comprised of 11 species that are common in slackwater habitats. They are typically found in shallow, clear to moderately turbid water with little current. Most species associate with some form of submerged cover. Spawning occurs in spring and early summer in shallow water. Sunfish deposit eggs in prepared nests, while others spawn along a sandy or clay substrate without parental care. The young often school and become pelagic, but return to shallow areas with submerged timber or aquatic vegetation as they grow. The fry consume plankton and later small crustaceans and insects. Fish are also eaten, particularly by the adult sunfish.

Group 5 - Generalist

This group of 20 species are considered generalists because they tolerate a wide range of environmental conditions including high turbidity, low dissolved oxygen, and high water temperatures. They are often the first inhabitants of disturbed habitats and can survive in isolated pools, but generally prefer shallow, sluggish waters with vegetation. Most have an extended spawning season throughout the spring and summer over a variety of substrates. Sunfish and bullheads prepare nests and guard the eggs, while others broadcast their eggs with no parental care. Mosquitofish eggs are fertilized internally, and females give birth to living young. The young of this group are usually confined to shallow, protected areas. The diet consists of plankton and invertebrates. Bullheads and sunfish will also consume small fishes.

(Sheet 4 of 4)

Table 2

Techniques Used to Determine Habitat Preferences of Fishes for Development of Suitability Index Curves

Technique	Reference
Mobile electroshocking devices	Jones, Orth, and Maughan 1984 Orth and Maughan 1982
Fixed electrodes	Larimore and Garrels 1985
Radiotelemetry	Larimore and Garrels 1985 Southall and Hubert 1984 Tyus, Burdick, and McAda 1984
Underwater/bank observation	Cunjak and Power 1986 DeGraff and Bain 1986 Greenberg and Holtzman 1987 Morantz et al. 1987 Moyle and Baltz 1985 Moyle and Vondracek 1985 Rankin 1986 Sheppard and Johnson 1985 Shirvell and Dungey 1983
Expert opinion (Delphi method)	Crance 1987
Controlled laboratory observations	Sechnick et al. 1986

Table 3

Example of Metrics Used in an Index of Biotic Integrity for Fishes in Northeast Louisiana

Category	Metric
Species richness and composition	Total number of fish species Number of darter species Number of sunfish species Number of sucker species Proportion of individuals as shad
Trophic composition	Proportion of individuals as omnivores Proportion of individuals as insectivorous cyprinids Proportion of individuals as top carnivores
Fish abundance	Number of individuals/0.5 acre

FISHERY HYDROACOUSTICS

Richard Kasul*

Introduction

Fishery hydroacoustics employs underwater sound for the remote detection of fish and habitat features. It provides a way to see below the water surface to accurately locate, characterize, and count fish and other underwater objects. Data from acoustic surveys are used to estimate a variety of fish community characteristics, including density and the spatial and size distribution of fish. In certain applications, fish movement patterns can also be measured (passage rates, direction of movement, and fish swimming speed).

Acoustics can be employed effectively in many different aquatic applications. It is uniquely suited for sampling in deepwater and fast-flowing environments where other fish sampling gears are not applicable. Extensive areas can be covered rapidly with a high degree of spatial detail. Normally inaccessible locations, such as areas near structures or inside underwater passageways, can be readily sampled. These characteristics allow acoustics to be used for sampling fishes in navigable waterways, in large deep reservoirs, and at hydropower dams. As a result, acoustics is a potentially useful tool for evaluating the status of fishes and the impacts on fishes associated with many kinds of water resource projects undertaken by the Corps of Engineers.

The intent of the workshop session described herein was to provide District personnel with sufficient background information to recognize situations in which hydroacoustics might be useful as a fish assessment tool. The session included an introduction to hydroacoustic principles, a description of basic instrumentation, and a discussion of fishery applications using mobile and fixed-location surveys.

Sampling with Echosounders

Hydroacoustic systems detect underwater objects by sensing echo returns from sound pulses transmitted through the water. The system transmits a

* US Army Engineer Waterways Experiment Station, Vicksburg, MS.

short-duration pulse, and then waits for echo returns for a period of time before the next transmission. The sound pulse, typically about 1 ft in length, spreads out as it travels through the water, forming a conically shaped sampling volume that is narrow at the source and widest at the farthest range. Many freshwater acoustic systems emit signals on a narrow 6-deg sampling beam that is only 1 m across at a distance of 10 m from the transmission source. The spreading phenomenon causes the sound intensity to diminish and the sampling volume to increase as the sound pulse travels farther from the source. These are only two of several factors that must be accounted for to provide accurate results.

A basic system consists of an echosounder and transducer. The echosounder initiates the transmission signal and processes returned echoes. The underwater transducer is a two-way device that physically transmits the sound pulse and senses any echo returns. The transmitted sound pulse is typically within a narrow frequency range that is well above the frequency of natural and most man-made sounds. Popular frequencies range from 38 kHz to several hundred kilohertz. The extremes offer a trade-off between signal losses and signal resolution. The lower frequencies are used in marine environments because they are less susceptible to signal decay in salt water. However, high frequencies can resolve smaller sized objects, so they are more commonly used in fresh water where signal decay is low. A popular freshwater system operates at 420 kHz. At this frequency, small scatterers such as insects and suspended particulates are resolvable. This frequency is well above the 18-kHz maximum that humans can hear and also well above the maximum auditory frequency of about 10 kHz that has been documented in fishes.

The ability to record data on tape is a valuable attribute of some fishery hydroacoustic systems. With appropriate interface equipment, a survey that is recorded in a digital format with a video cassette recorder can be exactly recreated for presentation to display devices or to echo-signal processors that are used to analyze survey data. Taping provides a permanent record of the survey; permits analysis of the data in the laboratory rather than the field, where effort can be focused on collection activities; and allows repeated reanalysis of the data using different analytical techniques or different processing criteria to maximize the information return from the collected data.

A visual representation of detected objects can be displayed on paper with a chart recorder. From a downward-looking transducer, the chart record, called an echogram, shows the transmission line near the surface and a bottom trace, which together delineate the water body. Fish and other objects in the water column are indicated by distinct echo traces in the water column. An annotated example showing the underwater profile of a submerged dike in the Mississippi River is presented as Figure 1. In this echogram, fish are concentrated in the velocity shelter of the plunge pool located on the downriver side of a dike. Because echograms give an accurate representation of position, objects such as fish, bottom, and cover can be accurately located for counting and spatial mapping. When echograms are digitized, fish density and spatial characteristics can be estimated for any designated habitat. Analysis of echograms, particularly counting and mapping of objects in the water, is a primary method of quantifying fish abundance and spatial distribution and cover characteristics.

Fish can also be counted automatically with signal processors that detect incoming echoes, evaluate echo characteristics against selection criteria established for fish, and then select and count valid fish targets. Automatic processing permits rapid screening of large amounts of data and allows control over the selection criteria used to define fish targets. Where fish occur in schools, individual fish may not be resolvable as separate targets; instead, they appear as an indistinct mass in the water column. In these circumstances it is common to index the density of fish using a technique called echo integration. A signal processor called an echo integrator measures the total echo intensity of fish in the ensonified region of water, and accumulates the total for successive pings. Integrators produce an acoustic measure that is thought to be roughly proportional to fish biomass. Integration provides comparative results that can be used to assess relative differences between different habitats, geographic locations, or survey periods.

Acoustic signal processors can also be used to estimate the target strength or the acoustic size of fish. Target strength is an inherent acoustical property of fish describing their ability to reflect sound. Most of the acoustic energy echoed from fish is returned from the skeleton and swim bladder. Larger fish, having more skeletal and swim bladder surface area, exhibit larger associated echo returns. Regression relationships between target strength and fish length have been developed to allow the approximate sizing of fish from acoustic measurements. Target strengths must be estimated in a way that accounts for angular variations in signal intensity across the

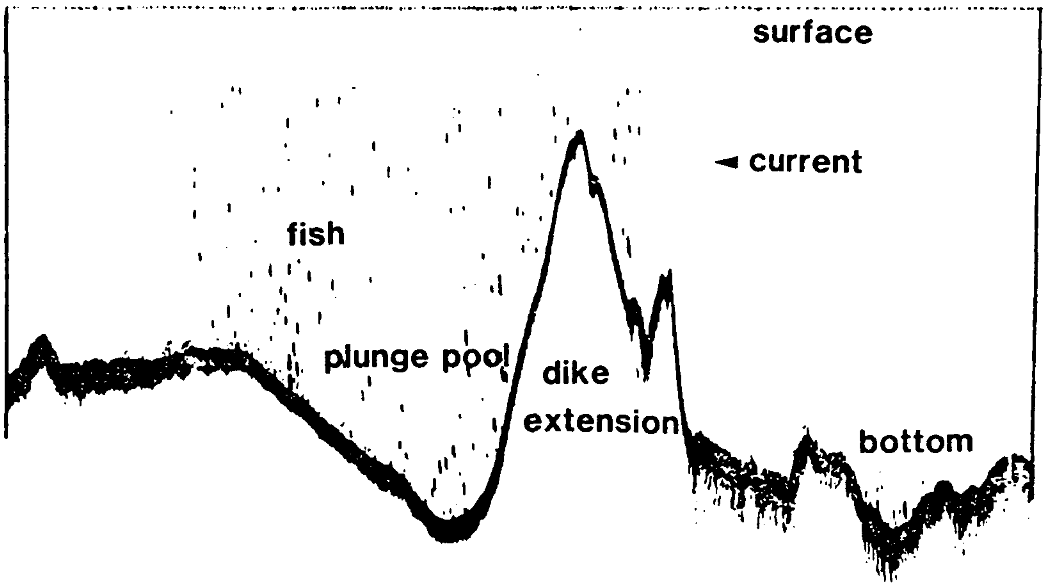


Figure 1. Sample acoustic echogram showing fish and underwater habitat features associated with a dike on the Mississippi River

diameter of the acoustic beam. The intensity is greatest in the center of the acoustic beam and diminishes toward the outer edge. This means that a small fish located directly on the central axis of the beam may produce an echo larger than a large fish at the edge of the beam. To correctly estimate the size of the fish, it is necessary to locate the angular position of the fish in the beam and apply a correction for the amount of beam falloff at that position. One type of system designed to directly measure the angular position targets, and therefore to permit direct calculation of target strengths, is referred to as the dual-beam system. This type of system uses two receiving transducer elements with different off-axis sensitivity patterns to detect echo returns. The two echo signals permit a type of triangulation to determine the target's off-axis position. Dual-beam acoustic systems provide better quantitative data than single-beam systems because of the additional information they collect. However, this comes at increased equipment cost and increased analysis time.

Fishery acoustic systems are scientific-grade instruments designed for performance and stability. Because of manufacturing variations, every acoustic instrument performs somewhat differently. Normally this would result in variations in the acoustic results from system to system; however, scientific systems are designed to permit a high level of calibration to known standards to account for these differences. High calibration standards make it possible to produce accurate quantitative results and ensure the comparability of data collected with different echosounders and transducers.

Mobile Survey Applications

Mobile surveys are used to characterize fish resources in water bodies such as rivers, reservoirs, or lakes. Mobile surveys often consist of a series of transects traversed by boat with the transducer suspended just below the water surface in a downward-looking direction. The transducer typically samples at a rate of 5 to 10 pings per second as the boat travels along the transect. The rapid ping rate causes successive pings to ensonify overlapping volumes of water so that a continuous wedge of water is sampled across the transect to capture everything from the near-surface to the bottom.

Mobile acoustic surveys effectively sample the open-water region of the water body. There is no practical limit to the maximum depth that can be sampled in freshwater environments; however, limitations do exist in shallow-water environments. From a downward-looking transducer suspended near the surface, there is typically a dead zone just below the surface and above the bottom that is not effectively sampled. These zones vary with instrument design and operation, but typically include areas 3 to 6 ft below the surface and 1 to 2 ft above the bottom. Methods are available to minimize the size of the dead area, but overall acoustics is less effective for sampling in extremely shallow-water environments.

Fixed-Location Survey Applications

Fixed-location surveying is a passive technique in which a stationary transducer is used to detect fish that swim through the beam. Fixed-location applications have been extensively developed for use around structures and for use in open water to measure passage rates, direction of travel, and swimming speed.

There is a considerable body of experience using fixed-location hydroacoustics at hydropower dams to monitor fish entrainment rates. Application of this technique is becoming popular to meet data-collection requirements of site relicensing at hydropower facilities. In hydropower applications, transducers are attached to the dam either inside or in front of the water intakes.

They remain in a fixed position so that they sample only those fish that pass through the beam.

Fixed-location applications in open-water situations have been used to monitor directional fish movements. Fixed-location transducers are mounted on platforms such as barges and used to monitor migration rates. Open-water monitoring has been employed to determine whether target species will migrate past project activities such as dredging operations.

Role of Acoustics in Fisheries Sampling

Acoustic applications provide an additional way to obtain more and better information about fish resources in a water body than the previously available sampling techniques. Acoustics is intended to provide quantitative data on fish abundance, distribution, movements, and size in a wide range of environmental conditions. In circumstances such as deep, fast-flowing rivers or in confined areas such as hydropower water intakes, acoustics is the only feasible method of obtaining quantitative fisheries data. It provides a method of sampling fishes rapidly to obtain extensive sample coverage in a short period of time and with a high degree of spatial detail. There is usually minimal interference with the fish surveyed; consequently, less gear bias is experienced as compared with many other sampling techniques.

Fish species are not directly identifiable with acoustic sampling. This can be a limitation in multispecies environments for which only one or two species are of interest or the species composition of the fish community is needed. However, verification of species is often possible using other sampling gears. Other methods can also be made more effective by acoustically locating the distribution of fish in advance of sampling.

DATA ANALYSIS AND INTERPRETATION

MEASUREMENT OF SIZE DEMOGRAPHY OF DOMINANT MACROINVERTEBRATE POPULATIONS FOR ENVIRONMENTAL ASSESSMENT AND MONITORING

Barry S. Payne*

Background

The condition of any population is determined by the net results of recruitment, growth, and mortality of the individuals that comprise the population. Direct assessments of population demography are often the most accurate and practical means of quantifying effects of man's activities on natural populations of aquatic macroinvertebrates. Recruitment, growth, and mortality processes can be assessed by measuring size demography of individuals comprising those populations. Such measurements are a fundamental analytical tool of population ecologists in basic and applied studies. Despite the established scientific credibility and practicality of such population assessments, the Corps of Engineers (CE) has not often used this approach in determinations of the effects of man's activities on stream-, river-, and lake-dwelling populations.

Purpose and Scope

In the present paper, three recent studies are briefly summarized to demonstrate how measurements of size demography of dominant macroinvertebrate populations can be used in quantitative assessment of the effects of CE activities on aquatic habitats. Each of these studies has been described in detail in other publications. The first example involves a one-time assessment of the size demography of 12 populations of the Asiatic clam, *Corbicula fluminea*, in Mississippi streams (Payne et al. 1989). Differences in the size structure of these populations provided evidence of differences in streambed stability at the 12 sites. The second example involves long-term monitoring of the size demography of the dominant mussel in the lower Ohio River, *Fusconaia ebena* (Payne and Miller 1989). This study was conducted in relation to concern about impacts of commercial navigation traffic on mussels in large inland waterways. The third example involves regular measurements of the density and

* US Army Engineer Waterways Experiment Station, Vicksburg, MS.

size structure of a population of a dominant larval insect, the caddisfly *Hydropysche orris*, on stone dikes in the lower Mississippi River. These measurements were used to quantify the production value of this important man-made habitat, and this value was compared to similar production estimates for caddisflies occurring on natural cobble riffles (Payne, Bingham, and Miller 1989).

Approach

All of the examples provided herein had a common aspect. Replicate quantitative samples were taken of substrate with benthic invertebrates such that all animals were obtained without bias due to size differences. Samples of small *H. orris* larvae from stone dikes were processed using fine-meshed nested sieves (0.25-mm minimum mesh opening). In contrast, samples of *C. fluminea* and *F. ebena* were processed using coarse-meshed nested sieves (minimum opening of 4 mm). The size structure of dominant populations was determined by measuring a linear aspect of each individual (e.g., interocular distance of caddisfly larvae and shell length of mussels) and preparing length frequency histograms for the entire population sample. A minimum of 60 individuals were collected and measured to characterize populations with simple size structure (i.e., one or two cohorts (generations) present at the same time), and 200 or more individuals were collected and measured to characterize populations with complex size structure (i.e., several cohorts present at the same time).

Example I: Size Demography of Clam Populations in Mississippi Streams in Relation to Streambed Stability

Background

The introduced Asiatic clam is widespread in North America and is often a dominant stream macroinvertebrate (McMahon 1983). The typical life history of *C. fluminea* leads to multiple cohorts that are simultaneously present in a population sample. In general, the life span of *C. fluminea* is approximately 18 to 36 months, and recruitment of juveniles to adult populations occurs over several months from early spring through late fall with two peaks of recruitment (usually occurring in spring and fall) (McMahon 1983). Thus, two cohorts are added to most populations each year. Survival of each of these cohorts for 18 to 36 months results in multiple cohorts in a shell length frequency histogram based on a sample of a typical population. Typically, three to five cohorts can be distinguished in the size structure of a long-established *C. fluminea* population.

C. fluminea is highly adapted to life in lotic habitats in which severe physical perturbations (e.g., streambed scour by spates and sustained emergency during droughts) can decimate precariously located populations (McMahon 1983). Soon after decimation, such populations often quickly reestablish in high density, due to the great dispersal capability of juvenile *C. fluminea*, small size (8 mm) and young age (<6 months) at first reproduction, hermaphroditism, and high fecundity. However, only in populations that are stable for 2 years or more is it possible for the typical complex size structure of *C. fluminea* to establish. Populations that are in early stages of colonization or recolonization have relatively simple size structure (one or two cohorts) and lack a high percent of large and relatively old individuals. Thus, the size structure of *C. fluminea* populations provides insight into the recent historical conditions of a particular stream location.

Methods and sites

The size demography of 12 lotic populations of *C. fluminea* in Mississippi was described based on a survey conducted in late May and June 1984 (Table 1). A special effort was also made at each site to obtain any large native unionids present. Unionids are sedentary and long lived (approximately 8 to 15 years for most species) (Coon, Eckblad, amd Trygstad 1977). Thus, presence of an adult population of unionids is indicative of long-term substrate stability (i.e., a site with unionids is highly unlikely to have suffered streambed scour during seasonal spates). Sand and gravel shoals of Mississippi streams and rivers are typically unconsolidated and easily eroded during spates. The distribution of unionids in the state is limited to portions of streams with stable substrate (Hartfield and Rummel 1981, Hartfield and Ebert 1986).

Stream discharge in Mississippi responds to seasonal patterns of rainfall. As indicated by the dotted line in Figure 1, discharge typically is high in winter and early spring and low during summer and early fall (USGS 1981; Tate et al. 1982, 1983; Tharpe, Morris, and Oakley 1984). Winter and spring discharge was unusually high throughout the state from December 1982 through mid-May 1983, and for a brief period in December 1983. High flows in 1983 broke historic records at two sites (BBL and BYP) (see Table 1 for site

Table 1

Description of Samples and Habitats of 12 Lotic Populations of *C. fluminea* Sampled in Mississippi During Late Spring and Early Summer of 1984

Site	Stream	Date	Sample Size	Substrate
BYP	Bayou Pierre	5 Jun	136	Along stumps and snags; with unionids
TAN	Tangipahoa R.	5 Jun	129	Sandy gravel along snags and macro-pytes; with unionids
PAS	Pascagoula R.	21 Jun	202	Mud, sand, and silt; with unionids
LEA	Leaf R.	21 Jun	196	Muddy sand; with unionids
CHU	Chunky R.	18 Jun	119	Mud over bedrock; with pisidiids
YOC	Yockanookany R.	7 Jun	136	Gravel where stabilized by stumps and snags
NOX	Noxubee R.	18 Jun	280	Unconsolidated riffles of mud, sand, gravel, and chalk flakes
PRL	Pearl R.	7 Jun	213	Detritus and sand among roots of cypress trees
BBL	Big Black R.	19 Jun	98	Sandbar in association with snags, limbs, and sticks
STR	Strong R.	24 May	145	Pockets of detritus and sand in scour holes in bedrock
BUT	Buttahatchie R.	18 Jun	102	Gravel shoals
CHI	Chickasawhay R.	21 Jun	413	Mud, sand, and broken clay at end of long run

descriptions) and approached record levels at several other of the 12 *C. fluminea* populations (Tate et al. 1983). Thus, extensive streambed scour was likely during the 18 months prior to the census of *C. fluminea* populations.

Results and discussion

Large *C. fluminea* (>20 mm shell length, SL) comprised a substantial fraction (13 to 64 percent) of only five of the 12 populations (Figure 2). These five populations (BYP, PAS, LEA, TAN, and CHU) also had complex size structure (i.e., three or more cohorts). The abundance of individuals greater than 20 mm SL and the complexity of size demography indicated longevity of 2 to 3 years for a substantial fraction of each population. These age estimates are based on Sickel's (1979) detailed life history study of a southern lotic population in the Altamaha River in Georgia. Individuals in the Altamaha River grew to average SL's of 14 and 22 mm in the first 12 and 24 months of life, respectively. Four of the five populations that include a

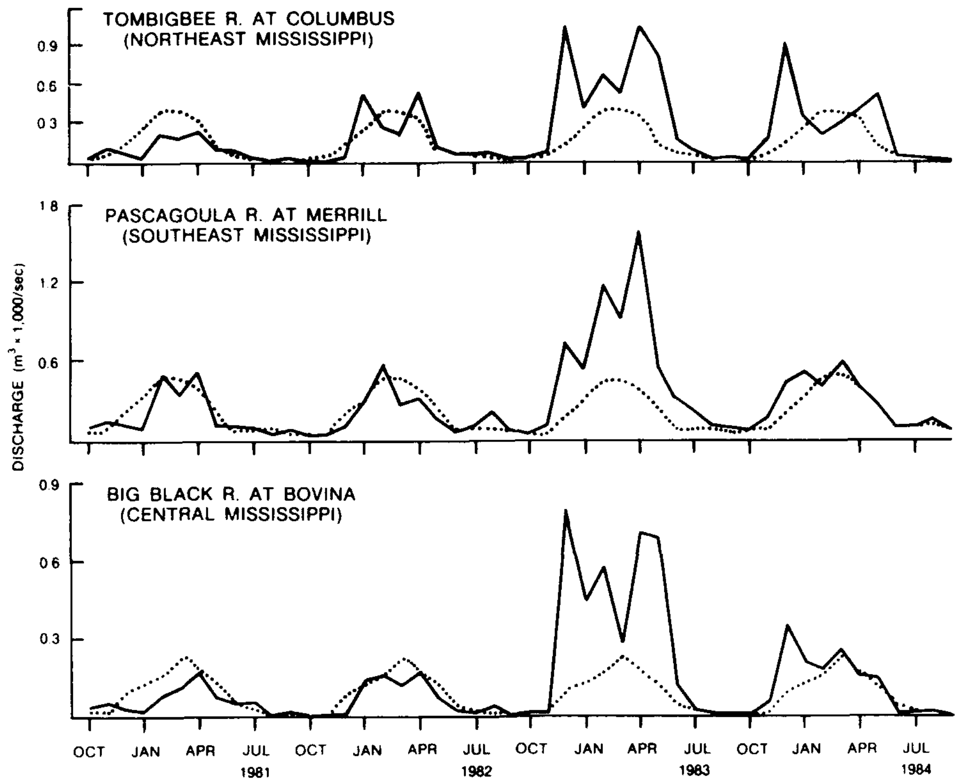


Figure 1. Median monthly discharge recorded from October 1980 through September 1984 at three representative gage stations in Mississippi (based on data in Tharpe, Morris, and Oakley 1984; Tate et al. 1982, 1983; and US Geological Survey 1981). The dotted line shows the median monthly discharge averaged for the period 1951-80

substantial number of older individuals (TAN, PAS, LEA, and BYP) occurred with populations of adult unionids (Table 1).

Shell length frequency histograms for the other seven populations of *C. fluminea* were overwhelmingly dominated by a single cohort of recent (1983) recruits with average SL's ranging from 9 to 12 mm (Figure 3). Individuals greater than 20 mm SL comprised only 0.2 to 4.9 percent of these populations with simple size structure. The lack of large clams and simple size structure, especially considered in light of the recent occurrence of record flood conditions, indicated that all seven populations were in an early colonization or recolonization stage. The lack of long-lived unionids at any of these seven sites also indicates that streambed instability is a potentially important habitat characteristic at these locations.

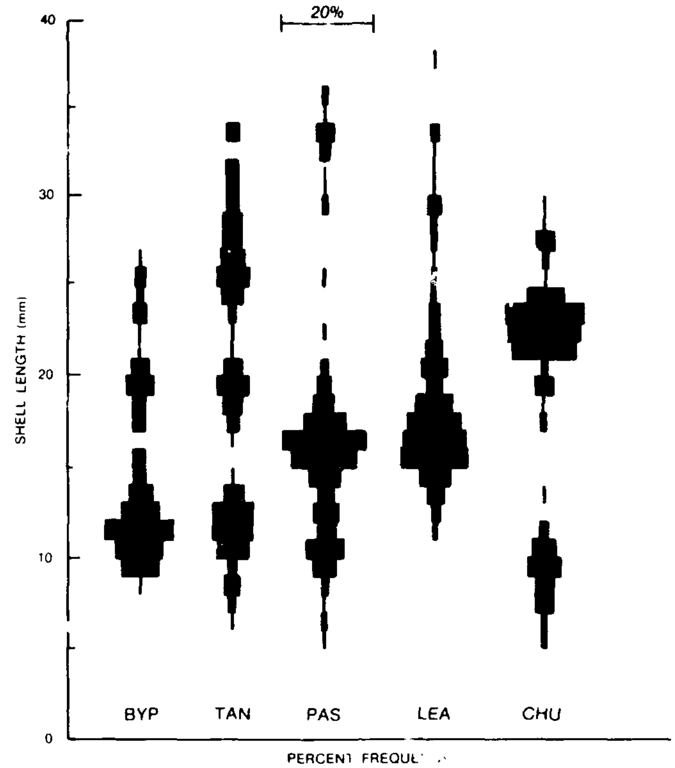


Figure 2. Shell length frequency histograms for five Mississippi populations of *Corbicula* with a substantial number of individuals greater than 20-mm SL and distinct multiple cohorts

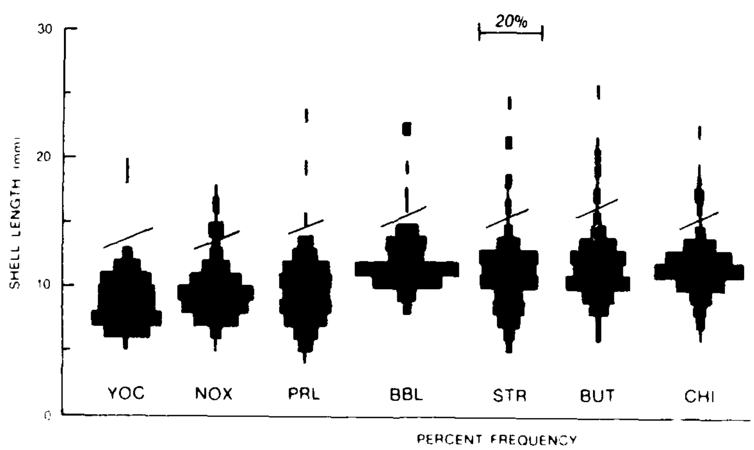


Figure 3. Shell length frequency histograms for seven Mississippi *Corbicula* populations dominated by individuals less than 20-mm SL that comprise an essentially single cohort of 1983 recruits. The slanted line through each histogram separates 1983 recruits from older individuals

Similar to these results for Mississippi *C. fluminea* populations, Diamond (1982) reported that the complexity of size demography of lotic populations of the snail *Juga plicifera* in the Pacific Northwest was inversely related to site susceptibility to streambed scour. A detailed population study of *C. fluminea* in the Altamaha River revealed marked differences in size demography of individuals from different sites within a 2,250-m river reach (Sickel 1979) that may have been related to local variation in streambed scour.

Corbicula fluminea is an excellent species for many biological assessments in streams. This introduced species is ubiquitous and often occurs in extremely high local abundance (McMahon 1983). At the individual physiological level, *C. fluminea* is extremely sensitive to several basic aspects of habitat conditions. For example, *C. fluminea* is less tolerant than native unionids to thermal stress, aerial exposure, or low dissolved oxygen conditions (McMahon 1983). However, the tremendous dispersal and recolonization capability of *C. fluminea* at the population level make studies at that level especially valuable for assessment of dynamic biological responses to changes in basic stream conditions. For example, McMahon and Williams (1986) showed that populations of *C. fluminea*, which were decimated by thermal stress in a lotic channel receiving heated effluent from an electricity-generating plant in Texas, quickly reestablished by downstream transport of small clams (mostly <4-mm SL) from unaffected areas upstream. Similarly, populations of *C. fluminea* in the New River, Virginia, that were killed by low water temperatures in winter rapidly reestablished the next spring by passive transport of small clams from unaffected upstream populations (Cherry et al. 1980). Clearly, comparison of the size demography of *C. fluminea* populations at different stream sites provides both highly quantitative and ecologically meaningful insights into biological assessments of stream conditions.

Example II: The Condition of a Mussel Bed in the Lower Ohio River as Assessed from Size Demography Data

Background

Mainstream river shoals are the principal habitat of most species of freshwater unionids (mussels). Demographically complete censuses have rarely been made of unionid populations in mainstream river shoals (Miller and Payne 1988), despite the great attention that has been focused on preservation of these animals. Quantification of recruitment, growth, and survival of naturally occurring cohorts in such populations will improve the ability of natural resource management agencies and the CE to protect the much-diminished yet still diverse assemblage of North American mussels that is threatened by habitat destruction, potential commercial overexploitation, and deleterious effects of various industrial, municipal, and navigational uses of inland waterways.

Methods and site

The mussel bed studied is located in the lower Ohio River downstream of Lock and Dam 53, the downstream-most impoundment of the Ohio River (Miller, Payne, and Siemsen 1986). This mussel bed is approximately 5 km in length and occurs on the channel border adjacent to the Ohio River navigation channel. *Fusconaia ebena* is the dominant mussel in this bed, comprising approximately two thirds of the total community. The size demography of this dominant population was assessed during each of the 3 years as part of a long-term monitoring study of this mussel bed (Payne and Miller 1989). Replicate quantitative samples of substrate were collected in the fall of 1983, 1985, and 1987 by divers equipped with scuba, and sieved to obtain all mussels regardless of size. The shell length of each mussel was measured, and SL frequency histograms were plotted.

Results and discussion

Seventy-one percent of all *F. ebena* collected in 1983 belonged to a single cohort of 1981 recruits with an average SL of 16 mm (range 13 to 20 mm) (Figure 4). By the fall of 1985 this cohort had increased in average SL to 30 mm (range 23 to 38 mm) and still comprised 71 percent of the total population of *F. ebena*. Continued linear growth of this cohort led to an average SL of 47 mm in late September 1987 (range 36 to 56 mm), and relative abundance of the cohort remained high (74 percent). The sustained high relative abundance of this cohort reflected its low mortality from 1983 to 1987 plus the lack of any extensive new recruitment of younger cohorts during that period (minor recent recruitment was indicated in the results of the 1987 sample) (Figure 4).

Much concern exists that increased frequencies of navigation traffic in inland waterways will deleteriously affect mussels via increased turbulence and resuspension of bottom sediments (e.g., Rasmussen 1979). This population of *F. ebena* in the lower Ohio River has existed for decades (Williams 1969) in a shoal bordering the commercial navigation lane. Data summarized in Figure 4

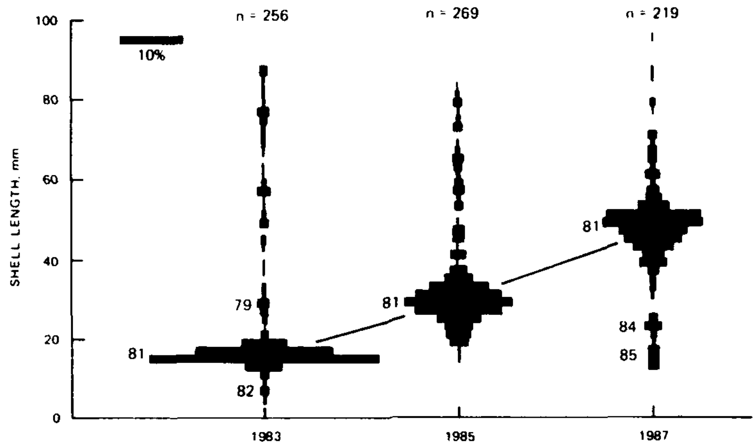


Figure 4. Shell length frequency histograms of *Fusconaia ebena* in the lower Ohio River on 28-29 September 1983, 31 October-1 November 1985, and 29-30 September 1987. The abundant 1981 cohort is labeled 81; total sample size is indicated above each histogram

clearly demonstrate that annual recruitment success is the principal determinant of the abundance of mussels in this shoal. Studies are continuing to determine what environmental factors were responsible for the exceptionally strong recruitment noted in 1981. Nonetheless, it is virtually impossible that navigation traffic determines recruitment patterns observed. Traffic rates have not substantially changed from 1981 to 1987, but mussel recruitment has varied annually by several orders of magnitude. In addition, survival of the 1981 recruits has been high despite the proximity of this shoal to a major commercial navigation lane.

The continued existence of most unionids in large inland rivers depends on protection of remaining beds and stable shoals from destruction by impoundment dredging, or sustained degradation of water quality (Stansbery 1970), as well as prevention of overharvesting of commercially exploited mussel beds. Assessments of the health of remaining mussel beds must be based on long-term quantitative studies of recruitment, growth, and survival of cohorts of dominant populations. Periodic assessment of size demography of *F. ebena* in the lower Ohio River (Figure 4) demonstrates how such measurements can allow quantification of recruitment, growth, and mortality rates.

Example III: Macroinvertebrate Production Estimates for Stone Dikes in the Lower Mississippi River

Background

Stones dikes are constructed by the CE to maintain the authorized navigation channel and reduce dredging requirements in the lower Mississippi River (LMR). These structures are constructed of riprap and protrude into the river obliquely or at right angles to the shore. Stone dikes have been identified as prominent and important aquatic habitat in the LMR (Beckett, Bingham, and Sanders 1983; Cobb and Magoun 1985). These structures provide diverse microhabitat for aquatic biota (Mathis, Bingham, and Sanders 1982). Rheophilic (flow-loving) organisms such as filter-feeding caddisflies and midges inhabit stone surfaces exposed to swift currents. Lentic species inhabit quiescent water in interstices among stones. Despite the diversity of microhabitats associated with dikes, the highest population densities are on stone surfaces exposed to swift currents (Mathis, Bingham, and Sanders 1982).

Productivity of dominant taxa (i.e., the quantity of animal biomass produced per unit area per unit time) can be assessed by consideration of density (individuals per unit area), biomass (weight per individual), and life history (growth rates and generations per year) (e.g., Russell-Hunter 1970). Productivity estimates provide a useful measure of habitat value important to higher trophic levels, including recreational and commercial fishes (e.g., Krueger and Waters 1983), and allow direct comparison of the value of dikes relative to naturally occurring substrates, such as cobble riffles, that support a similar fauna (e.g., Parker and Voshell 1983).

The purpose of the present example is to summarize how regular assessments of the density and size demography of the caddisfly *H. orris* led to a quantitative estimate of the production value of stone dikes in the LMR. *H. orris* are abundant on coarse-grained substrate exposed to swift currents (e.g., Benke et al. 1984) and are dominant macroinvertebrates on dikes in the LMR (e.g., Mathis, Bingham, and Sanders 1982).

Method and site

Regular (approximately monthly) sampling was conducted from September to November 1987 and May to October 1988. On each date, three to five 10-kg stones were obtained from high-velocity water (approximately 1 m/sec) near the tip of each of two dikes in the Cracraft and Leota dike systems of the LMR at river miles 510 and 515 in Washington County, Mississippi. In the laboratory, all macroinvertebrates were brushed from each stone, counts were made of all macroinvertebrates including *H. orris*, and the surface area of each stone was determined (Payne, Bingham, and Miller 1989). Without bias toward large or small individuals, approximately 200 *H. orris* were measured for interocular distance (IO) using a binocular dissecting microscope. A length frequency histogram was prepared from IO measurements of each month, and representative individuals of the full size range of *H. orris* were used to determine length-to-dry weight relationships needed for production computations.

Results and discussion

Five larval instars were easily distinguished in IO frequency histograms (Figure 5). The percent abundance of each larval instar was plotted for each sampling date, and analysis of this plot led to the determination that *H. orris* exhibited a bivoltine life cycle (i.e., two generations per year with the spring generation giving rise to and being completely replaced by a fall generation) (Figure 6). Production computations (explained in detail by Payne et al. 1989) were based on combined consideration of the duration of larval life spent in each larval instar (estimated from Figure 6) plus measurements of the density and average individual dry weight of each instar. Computation of production of the spring and fall generation is outlined in Table 2. Annual production (equal to the sum of production of each to the two generations per year) was 10.1 g/m^2.

This production value closely matches those that have been computed for hydropsychid caddisfly populations on naturally occurring coarse-grained substrates in streams and rivers. Published production estimates for such populations range from 1 to 37 g/m^2 (average = 13 g/m^2) (Krueger and Waters 1983, Parker and Voshell 1983, Mackay and Waters 1986). It is noteworthy that annual production of filter-feeding caddisfly populations can reach extraordinarily high levels (maximum reported value of 224 g/m^2) immediately downstream of river impoundments with surface releases of seston-enriched water (Parker and Voshell 1983, Mackay and Waters 1986). Excluding sites affected by seston-enriched discharge from impoundments, annual production of hydropyschid caddisflies on natural cobble riffles is very similar to that estimated for *H. orris* on LMR dikes.

As of September 1988, 221 miles of dikes had been constructed in the LMR (Payne, Bingham, and Miller 1989). Production estimates based on regular estimates of density and size demography of dominant larval insect populations, such as *H. orris*, on representative dikes demonstrate that these

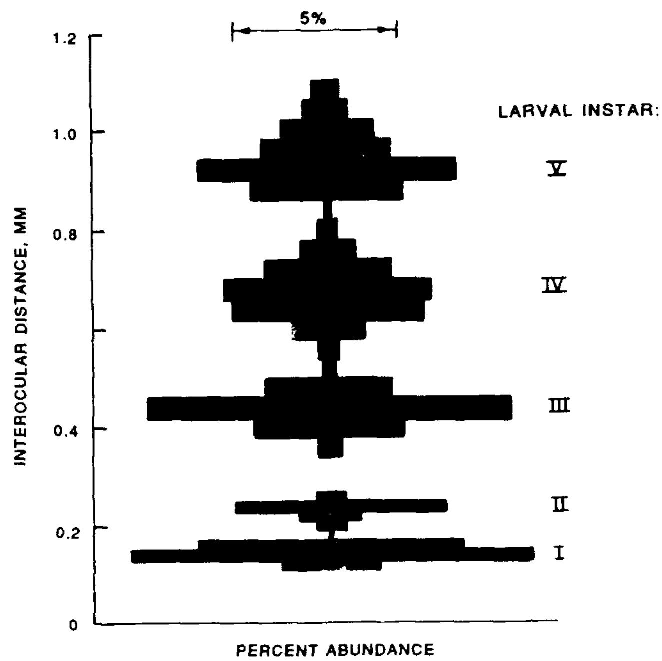


Figure 5. Five instars of *H. orris* as delineated by interocular distance measurements

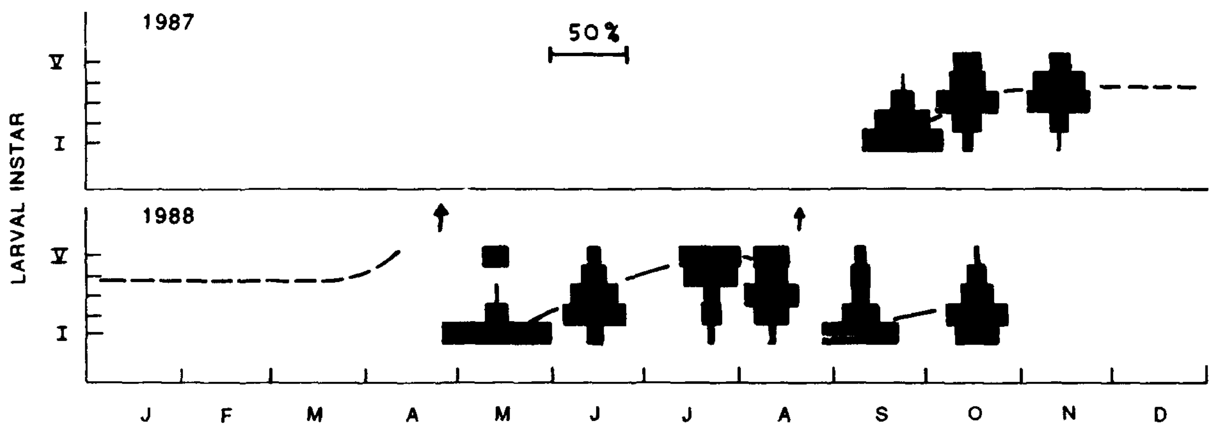


Figure 6. Seasonal changes in the relative abundance of larval instars of *H. orris* on LMR dikes. Arrows indicate peak emergence periods

Table 2

Average Standing Crop (B) and Production (P) of the Bivoltine

Hydropsyche orris Population on LMR Dikes

Larval Instar	Density (Ind./m^2)	Dry Weight (µg/Ind.)	Standing Crop (g/m^2)	Density Loss per Instar (Ind./m^2)	Dry Weight at Loss (µg/Ind.)	No. of Times Loss Occurs	Production (g/m^2)
			Spring Generation				
I	2,089	9	0.018	704	19	5	0.067
II	1,385	41	0.057	240	85	5	0.102
III	1,145	175	0.200	138	313	5	0.216
IV	1,007	561	0.565	224	897	5	1.005
V	783	1,434	1.123	783	1,702	5	6.663
			B = 1.963				P = 8.053
			Late-Summer Generation				
I	837	9	0.008	472	19	5	0.045
II	365	41	0.015	85	85	5	0.036
III	280	175	0.049	51	313	5	0.080
IV	229	561	0.129	15	897	5	0.067
V	214	1,434	0.307	214	1,702	5	1.821
			B = 0.508				P = 2.049

Annual production of *H. orris*: 10.102 g/m^2

structures provide a valuable substrate for aquatic macroinvertebrates that are important in the nutrition of fishes and other vertebrates of recreational and ecological value.

Summary

These three examples demonstrate the variety of quantitative and ecologically meaningful assessments that can be based on measurements of the size demography of dominant populations of aquatic macroinvertebrates. Recruitment, growth, mortality, and production estimates are all founded on such population assessments. Both one-time censuses (e.g., the *Corbicula fluminea*) and repeated censuses (e.g., the *Fusconaia ebena* and *H. orris*) can lead to important quantitative assessments of biological conditions in relation to Corps of Engineers activities in aquatic habitats. Biological assessments summarized herein were of streambed stability in relatively small rivers and streams in Mississippi, navigation traffic effects in the Ohio River, and production value of stone dikes in the lower Mississippi River. The basic and quantitative ecological information provided on life history of dominant macroinvertebrates during each of these assessments should remain valuable for future evaluations of the same habitats.

Assessments at the population level of biological organization are especially valuable in applied studies. Biological effects of CE activities in aquatic habitats can also be assessed at the organismal or community (groups of co-occurring populations) levels of organization. Studies at the individual level often lack ecological relevance without confirmation of effects at the population or community level. For example, mortality of individual organisms often has no discernible effect due to compensatory responses in population dynamics. Community-level studies, although of clear ecological relevance, are greatly hindered by the prevalence of locally uncommon species in nearly all natural communities. This makes completely accurate sampling of communities (especially with replication) practically impossible. Accurate and replicated sampling of dominant populations is much more feasible. Not surprisingly, the most convincing conclusions of many community studies are those based on analysis of responses of dominant populations. As demonstrated herein, size (and age) structure are among the most important and practical measurements that can be made of dominant populations.

References

Beckett, D. C., Bingham, C. R., and Sanders, L. R. 1983. "Benthic Macroinvertebrates of Selected Habitats of the Lower Mississippi River," Journal of Freshwater Ecology, Vol 2, pp 247-261.

Benke, A. C., Van Arsdall, T. C., Gillespie, D. M., and Parrish, F. K. 1984. "Invertebrate Productivity in a Substropical Blackwater River: The Importance of Habitat and Life History," Ecological Monographs, Vol 54, pp 25-63.

Cherry, D. S., Rodgers, J. H., Jr., Garney, R. L., and Cairns, J., Jr. 1980. "Dynamics and Control of the Asiatic Clam in the New River, Virginia," Virginia Polytechnic Institute and State University, Bulletin No. 123, Blacksburg, VA.

Cobb, S. P., and Magoun, A. D. 1985. "Physical and Hydrological Characteristics of Aquatic Habitat Associated with Dike Systems in the Lower Mississippi River, River Mile 320 to 610, AHP," Lower Mississippi River Environmental Program, Report 5, Mississippi River Commission, Vicksburg, MS.

Coon, T. G., Eckblad, J. W., and Trygstad, P. M. 1977. "Relative Abundance and Growth of Mussels (Mollusca: Eulamellibranchia) in Pools 8, 9, and 10 of the Mississippi River," Freshwater Biology, Vol 7, pp 279-285.

Diamond, J. M. 1982. "Stream Geomorphology and Benthic Habitat Predictability as Determinants of the Population Dynamics and Life History of the Snail *Juga plicifera*," Journal of Freshwater Ecology, Vol 1, pp 577-588.

Hartfield, P. D., and Ebert, D. 1986. "The Mussels of Southwest Mississippi Streams," American Malacological Bulletin, Vol 4, pp 21-23.

Hartfield, P. D., and Rummel, R. G. 1981. "Mussels of the Big Black River," Mississippi Academy of Science Abstracts, Vol 26, p 128.

Krueger, C. C., and Waters, T. F. 1983. "Annual Production of Macroinvertebrates in Three Streams of Different Water Quality," Ecology, Vol 64, pp 840-850.

Mackay, R. J., and Waters, T. F. 1986. "Effects of Small Impoundments on Hydropyschid Caddisfly Production in Valley Creek, Minnesota," Ecology, Vol 67, pp 1680-1686.

Mathis, D. B., Bingham, C. R., and Sanders, L. G. 1982. "Assessment of Implanted Substrate Samplers for Macroinvertebrates Inhabiting Stone Dikes of the Lower Mississippi River," Miscellaneous Paper E-82-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

McMahon, R. F. 1983. "Ecology of an Invasive Pest Bivalve, *Corbicula*," Ecology; Vol 6, The Mollusca, W. D. Russell-Hunter, ed., Academic Press, Orlando, FL.

McMahon, R. F., and Williams, C. J. 1986. "Growth, Life Cycle, Upper Thermal Limit and Downstream Colonization Rates in a Natural Population of the Freshwater Bivalve Mollusc *Corbicula fluminea* (Muller) Receiving Thermal Effluents," Proceedings, Second International *Corbicula* Symposium, American Malacological Bulletin, Special Edition No. 2, pp 231-239.

Miller, A. C., and Payne, B. S. 1988. The Need for Quantitative Sampling to Characterize Size Demography and Density of Freshwater Mussel Communities," American Malacological Bulletin, Vol 6, pp 49-54.

Miller, A. C., Payne, B. S., and Siemsen, T. S. 1986. "Description of Habitat of the Endangered Mussel *Plethobasus cooperianus*," Nautilus, Vol 100, pp 14-18.

Parker, C. R., and Voshell, J. R., Jr. 1983. "Production of Filter-Feeding Trichoptera in an Impoundment and a Free-Flowing River," Canadian Journal of Zoology, Vol 61, pp 70-87.

Payne, B. S., Bingham, C. R., and Miller, A. C. 1989. "Life History and Production of Dominant Insects on Stone Dikes in the Lower Mississippi River," Lower Mississippi River Environmental Program, Report 18, Mississippi River Commission, Vicksburg, MS.

Payne, B. S., and Miller, A. C. 1989. "Growth and Survival of Recent Recruits to a Population of *Fusconaia ebena* (Bivalvia: Unioridae) in the Lower Ohio River," Vol 121, pp 99-104.

Payne, B. S., Miller, A. C., Hartfield, P. D., and McMahon, R. F. 1989. "Variation in Size Demography of Lotic Populations of *Corbicula fluminea* (Muller)," Nautilus, Vol 103, pp 78-82.

Rasmussen, J. L. 1979. "A Summary of Known Effects and a Priority List of Data Gaps for the Biological Effects of Navigation on the Upper Mississippi River," US Fish and Wildlife Service Report to the US Army Engineer District, Rock Island, Rock Island, IL.

Russell-Hunter, W. D. 1970. Aquatic Productivity: An Introduction to Some Aspects of Biological Oceanography and Limnology, Collier-Macmillan London.

Sickel, J. B. 1979. "Population Dynamics of *Corbicula* in the Altamaha River, Georgia," J. C. Britton, ed., Proceedings, First International *Corbicula* Symposium, Texas Christian University Research Foundation, Fort Worth, TX.

Stansbery, D. H. 1970. "Eastern Freshwater Mollusks (I), the Mississippi St. Lawrence River System," Contribution No. 2, Symposium on Rare and Endangered Mollusks, Malacologia, Vol 10, pp 9-22.

Tate, C. H., Tharpe, E. J., Bednar, G. A., and Oakley, W. T. 1982. "Water Resources Data: Mississippi Water Year 1983," US Geological Survey, Water Data Report MS-82-1, Jackson, MS.

Tate, C. H., Tharpe, E. J., Bednar, G. A., and Oakley, W. T. 1983. "Water Resources Data: Mississippi Water Year 1983," US Geological Survey, Water-Data Report MS-83-1, Jackson, MS.

Tharpe, E. J., Morris, F., III, and Oakley, W. T. 1984. "Water Resources Data: Mississippi Water Year 1984," US Geological Survey, Water-Data Report MS-84-1, Jackson, MS.

US Geological Survey. 1981. "Water Resources Data: Mississippi Water Year 1981," Water-Data Report MS-81-1, Jackson. MS.

Williams, J. C. 1969. "Mussel Fishery Investigations, Tennessee, Ohio, and Green Rivers," US Fish and Wildlife Service and Kentucky Department of Fish and Wildlife Resources, Frankfort, KY.

APPLICATION OF TECHNIQUES

FISHERY INVESTIGATIONS

J. R. Gammon*

Introduction

Riverine aquatic ecosystems operate within a highly changeable chemical/physical environment. Short-term investigations may yield interesting results, but only long-term studies are likely to produce meaningful ecological information.

The aquatic communities of the middle Wabash River and its tributaries, emphasizing the fish communities, have been studied annually since 1967. Initial assessments were directed toward thermal effects in two limited sections of the river main stem. The research was extended in 1973 to include 160 miles of main stem and several important tributaries. Some macrobenthic, periphyton, and phytoplankton work has been undertaken, but the fish community has been studied most intensively. Although the Wabash River supports an abundant mussel community, this component was not included because of time and funding constraints.

Methods

A variety of collecting methodologies for fish have been employed, and it was determined that pulsed d-c electrofishing is most effective for the greatest number of large species in the Wabash River. Fish are collected three times each summer from 63 stations, each of which is 0.5 km long. Most stations are sited in relatively fast water with good cover and depths of 1.5 m or less. A Smith-Root electrofisher produced 400 volts-direct current and 120 pulses per second fed into an electrode system consisting of two circlets of short stainless steel anodes suspended at the water surface by bow booms and two gangs of long woven copper cathodes hung from the port and starboard gunwales.

---

* Department of Biological Sciences, DePauw University, Greencastle, IN.

Major Findings

The investigations have contributed toward the development of an objective quantitative community index that reflects the "quality" of a fish community. It was found that there was considerable variation in community composition through space and time, but that most community indices tended to vary in similar fashion. A good fish community is one with both an abundance of individuals and a high diversity of species; therefore, a Composite Index of Well-Being (I_{wb}) was devised to quantitatively represent the catch samples. It is calculated as

$$I_{wb} = 0.5 \ln N + 0.5 \ln W + Div._{no.} + Div._{wt.}$$

where

N = number of fish captured per kilometer

W = weight (kg) of fish captured per kilometer

$Div._{no.}$ = Shannon diversity based on numbers

$Div._{wt.}$ = Shannon diversity based on weight

For the sampling methodology that we use, there is a good correspondence of high community values with excellent fish communities and low community values with poor fish communities. These, in turn, are primarily the result of differences in water and habitat quality and flow regime. Table 1 summarizes these findings.

The overall fish community in the middle river improved from 1973-75 to 1985-87. The upper reaches improved from Fair to Good/Excellent while the lower reaches improved from Poor to Fair. Most species populations, except for carp and gizzard shad, improved markedly. From 1974 through 1983 the combined catch rate of white bass, channel catfish, the centrarchid bass (smallmouth, spotted, and largemouth), sauger, and walleye averaged slightly more than one fish per kilometer electrofishing effort (1.087, with a range from 0.39 to 1.85). More recently, the average catch rate of these species increased to 3.68/km (1984), 9.11/km (1985), and 12.35/km (1986). This rate declined to 6.78/km in 1987, but increased again in 1988 to 10.7, indicating relative stability over the past 4 years.

Many other desirable fishes also increased, most in the upper river, but some in the lower river. Species that reproduce and live in the main stem (e.g. channel catfish, flathead catfish, sauger, spotted bass, mooneye,

Table 1

Community Parameters and Qualitative Aspects of Fish Communities

Parameter	Excellent	Good	Fair	Poor
		Community Parameters		
I_{wb}	>8.5	7.0-8.5	5.5-7.0	<5.5
Avg. No. Species	>15	8-15	5-8	<5
No./km	>100	60-100	25-60	<25
Kg/km	>50	25-50	15-25	<15
Div.(no.)	>2.2	1.7-2.2	1.3-1.7	<1.3
Div.(wt.)	>2.0	1.5-2.0	1.1-1.5	<1.1
Even.(no.)	. . . .	(0.75 to 0.90)	. . . .	
Even.(wt.)	. . . .	(0.70 to 0.80)	. . . .	
		Sport Fish*		
No./km	>20	12-20	4-12	<4
		Trophic Composition		
%wt. Piscivores	. . . .	(15 to 30)	. . . .	
%wt. Insectivores	>30	15-30	5-15	<5
%wt. Herbivores	<10	10-20	10-20	>20?
%wt. Detritivores	>5	2-5	1-4	<1

* Centrarchid basses, white bass, flathead catfish, channel catfish, sauger, walleye, sunfish, and crappie.

goldeye, northern river carpsucker, blue sucker, and drum) increased greatly in density. Species that enter the main stem from offstream reservoirs (white bass and walleye) also increased significantly. Species entering from clean tributaries (smallmouth bass and longear sunfish) also increased.

At the same time, populations of carp and gizzard shad have decreased. It appears that the recent decline in gizzard shad may be related to the increased predator pressure from expanded piscivore populations.

Some populations (e.g. blue sucker, mooneye, and spotted bass) expanded into hitherto unoccupied areas of the river. There was also an increase in the average size for many species, opening questions of greater longevity, faster growth, etc. These possibilities remain to be explored.

These recent improvements in the community may have resulted from a combination of long-term 50-percent reduction in biological oxygen demand (BOD) loading, a low-flow summer facilitating good reproduction and survival through the first year for many species of fish, and possibly also by an acute (25 percent) reduction in agricultural loadings to the river during the 1983

Payment in Kind program. The reductions in BOD are probably related to improved industrial and municipal waste treatment.

In addition to examining long-term changes in population abundance, community composition, and geographic distribution, the studies have been useful in (a) distinguishing natural from man-induced perturbations, (b) locating problem areas in the river, and (c) evaluating the effects of changes in operating procedures at point sources of pollution.

It has been found that good reproduction and survival through the first year of life in species of fish that reproduce in the main stem are related to low summer flow during the months of June and July. Population levels of many species were lowest in 1983, following several years of higher than normal flows. Three years later, the population levels rose to their highest level ever.

There appears to be an inverse relationship between the quality of fish community and dissolved oxygen (DO) levels. The decreased BOD loading of the river has been mentioned. One way of characterizing a river with respect to its dissolved oxygen status is to determine its DO deficit through computer models. The hypothetical low-flow DO deficit due to several oxygen-using processes was derived by HydroQual from data obtained in 1981 and 1982 through a multidisciplinary effort involving the Indiana Department of Environmental Management, industries, and universities.

Using the DIURNAL Model, the DO deficit during periods of low flow in the upper river was projected to be approximately 2.0 to 2.5 mg/ℓ. This increases to about 4.0 mg/ℓ in the lower reaches. Phytoplankton respiration is responsible for about 50 to 60 percent of the DO deficit in the upper reaches and about 70 percent in the lower reaches. The second largest DO sink is cBOD, which enters the river from multiple point sources and accounts for about 10 percent of the DO deficit in the upper and over 15 percent in the lower reaches. Sediment oxygen demand is also important and is strongly related to phytoplankton abundance as well as other suspended organic materials.

We found that phytoplankton may indirectly affect the fish community by reducing DO concentrations in some parts of the river. There are interactions during low-flow periods between (a) river morphology, (b) large diatom populations sustained by nutrient inputs, and (c) thermal loading. The sequence of development described below occurs in a 6-mile section of river dammed by gravel from Sugar Creek.

When flows diminish to about 1,500 cfs, a sharp increase in phytoplankton density occurs. In a 4-day period of stable low flow, the chlorophyll-*a* increased from about 160 to nearly 230 μg/l. As the water passed through the ponded segment, significant amounts of phytoplankton settled to the bottom, with chlorophyll-*a* decreasing to less than 150 $\mu g/\ell$, and Secchi transparency increased as suspended materials settled out. Total nonfilterable solids decreased from about 80 to about 50 mg/ℓ. The phytoplankton settled beyond the limits of light penetration, where they died and decomposed. This resulted in a decrease in DO and caused a significant disruption of the fish community in 1977 and 1983.

The data are also of value in evaluating the effectiveness of changes in waste treatment or operating procedure. For example, one electric generating station began operating its cooling facilities continuously when the ambient river water temperatures reached 78° F. The I_{wb} at this site improved, while it declined in all other reaches. Furthermore, there was a return to the area of several species that had not been common for many years, including smallmouth buffalofish, redhorse, blue sucker, and sauger.

Based on the changes in fish community we have seen, monitoring frequency should be no less than every 3 years. Major shifts in population size and community structure would have been missed at longer intervals. The fish community was quite stable during the entire summer and into fall. However, rather large changes sometimes occurred within a few weeks, as a result of local stress. Therefore, it is best to include more than one series of collections in order to characterize the fish community during the summer and early fall.

HEXAGENIA MAYFLIES (EPHEMEROPTERA: EPHEMERIDAE): BIOLOGICAL MONITORS OF WATER QUALITY IN THE UPPER MISSISSIPPI RIVER*

Calvin R. Fremling**

Introduction

Hexagenia mayflies are vital members of many freshwater ecosystems. I became interested in them in 1956 when, as a graduate student at Iowa State University, I was asked to investigate a nuisance "river bug" problem at Keokuk, IA, the site of the largest lock and dam on the Mississippi River (MR). The main nuisance insect species were *Hexagenia* mayflies (which dominated the silted river bottom in the impoundment behind the dam) and several species of hydropsychid caddisflies (which thrived in the fast water of the rocky tailwaters). The life histories and ecology of the nuisance species were relatively unstudied, and I spent the next 3 years working with them, subsequently devoting 30 additional years to the study of *Hexagenia* mayflies and MR ecology (Fremling and Claflin 1984). My research has led me from the source of the MR at Lake Itasca to many lakes and tributaries within the watershed, and downstream to the Gulf of Mexico.

In 1958, ship captains, lock masters, and interested river residents were solicited to collect adult mayflies during mass emergences along the MR and its tributaries (Fremling 1973). This system, used annually through 1969, was reemployed in 1976, 1986, and 1988. The resultant mayfly distribution patterns have been used to monitor habitat quality. Ideally, water quality investigations should include chemical and physical testing of water and sediments at many locations throughout the year, as well as qualitative and quantitative analyses of zoobenthic communities (Hilsenhoff 1987). However, such comprehensive studies are usually not logistically feasible or affordable on large river systems.

Hexagenia mayflies have proven to be good monitors of water quality because of their long nymphal lives and intimate association with organically enriched sediments where toxins accumulate. They are especially vulnerable to hypoxia, which may kill them directly or cause them to abandon their burrows,

---

* First published in Journal of the Minnesota Academy of Science, Vol 55, No. 1, pp 139-143.
** Department of Biology, Winona State University, Winona, MN.

subjecting them to predation by fish (Fremling 1970). While chemical tests provide instantaneous descriptions of water and sediment quality in terms of specific parameters, mayfly distribution assesses the synergistic effects of hypoxia, toxins, and other stresses throughout the year. In addition to being economical in terms of time, money, and resources, the method has been educational for the general public. River residents have come to associate mayflies with water quality, realizing that their presence does not prove that the river is clean enough to drink or to swim in, but that it is in good biological condition. *Hexagenia* distribution has been drastically altered by humans in recent years; pollutants have eliminated the insect from portions of Lake Michigan's Green Bay (Lee 1962), Lake Huron's Saginaw Bay, most of Lake Erie (Britt 1955, Beeton 1961, Carr and Hiltunen 1965), and segments of the Illinois and MR (Fremling 1964; Mills, Starrett, and Bellrose 1966; Fremling 1970). Pronounced declines in the abundance of *Hexagenia* in lakes are mainly due to eutrophication (Rasmussen 1988).

Hexagenia adults recently have been used to monitor levels of polychlorinated biphenyls (PCBs) along the Upper Mississippi River (UMR) (Mauck and Olson 1977, Clements and Kawatski 1984). Presently, *Hexagenia* adults and nymphs from the UMR are being tested at several area laboratories for heavy metals and chlorinated hydrocarbons. Nymphs are also used as bioassay organisms in toxicity tests (Fremling 1975; Bills, Marking, and Rach 1985). Laboratory culture methods have been developed (Fremling 1967), as well as artificial substrates, testing apparatus, and protocol (Fremling and Schoening 1973; Fremling and Mauck 1980; Henry, Chester, and Mauck 1986). Nymphs for laboratory study can be purchased by mail, and a film on the ecology of the insect is available (Encyclopaedia Brittanica 1973).

General Mayfly Life History

Mayflies have fascinated man for centuries because of the brief span of their adult lives. They spend most of their lives as aquatic nymphs or naiads (the British call them larvae) in a wide variety of standing and running freshwater habitats, then develop into winged stages that mate, lay eggs, and soon die. Although a few species survive as adults for a week or more, most have an adult life of only a day or two. This brevity of life is implied in their order name, Ephemeroptera, for the winged stages are indeed ephemeral. When the winged adult emerges from the nymph it is called a subimago, which later molts into the final winged stage or imago. Mayflies are the only insects that molt as adults. The mouthparts and digestive tract of the adult are vestigial; all feeding is done in the nymphal stage.

Mayflies are very habitat specific, yet they are almost worldwide in their distribution, being absent only from Antarctica, the extreme Arctic, and small oceanic islands. All but three of the 20 families in the world occur in North or Central America. Taxonomists have listed about 625 species of mayflies from North America north of Mexico. Worldwide, about 1,800 species have been described, and new species are being identified each year (Edmunds, Jensen, and Berner 1976). Trout fishermen have long been the most avid amateur students of mayflies, skillfully tying artificial flies to "match the hatch" and keeping detailed record of when "hatches" occur on the streams they fish.

The real economic value of mayflies lies in their importance in the food webs of inland waters. The nymphs are mainly plant eaters, converting algae, rooted vegetation, and plant debris into high-quality fish food. Most mayflies are eaten as nymphs, but fish also consume them as they rise to the surface to emerge as adults. Once on the wing, mayflies are eaten by bats, birds, spiders, and predaceous insects. Females returning to the water to lay their eggs are again subject to predation by fish.

The durability, adaptability, and tenacity of mayflies are affirmed by their long existence on earth. They predate dinosaurs, occurring in the fossil record of the Carboniferous Period and becoming abundant during the Permian. Their distribution even provides excellent biological support for the theory of plate tectonics (Peters 1988). Mayflies have survived the periodic mass extinctions that destroy many other species of animals. The greatest threat to their existence has been pollution caused by man.

Ecology of *Hexagenia* mayflies

The biology of *Hexagenia* mayflies has been studied quite thoroughly (Needham, Traver, and Hsu 1935; Hunt 1953; Fremling 1960; Swanson 1967). Invasions by hoards of the large insects are familiar phenomena on warm summer evenings along the UMR. Drifts of the insects form under street lights, often blanketing parked cars. Traffic is impeded, shoppers desert the streets, and in extreme cases, snow plows are called out to reopen highway bridges that have become impassable. Drifts of decaying mayflies smell like rotting fish, hence the common name "fish fly." Subimagoes usually emerge from the water at night, fly to trees along the shore, and remain motionless during the following day, usually moving only when disturbed or to keep themselves shaded. The adult molt begins in the afternoon, peaking about 4 p.m. The resultant imagoes are noticeably more delicate than the subimagoes, but their powers of flight are greater.

Mating swarms form along the riverside in the evening, and copulation takes place in flight. The males usually remain near the mating area, but the females fly upstream to lay their eggs (Fremling 1968), apparently flying until they have exhausted their energy reserves. They may travel several miles, depending on air temperature and wind, and then land on the water surface. Each female lays two packets of eggs, each containing about 4,000 eggs. The eggs separate from each other, sift slowly to the silted riverbed, and hatch in about 12 days, depending on water temperature (Flattum 1963). Most nuisance problems are created by females being diverted to light sources during their oviposition flight. Problems have been lessened in recent years by the use of sodium vapor lights whose longer wavelengths are less attractive to most insects.

Hexagenia nymphs are easily recognized by large mandibular tusks, broad forelegs modified for digging, and feathery gills on the dorsum of the abdomen. They dig U-shaped burrows in the silted bottom of lakes, rivers, and streams. In addition to providing seclusion, the burrows function as respiratory tubes as the nymphs pump water through them with undulatory gill movements. Because nymphs are highly sensitive to hypoxia, they occur below the thermocline only in lakes that have sufficient hypolimnetic dissolved oxygen (DO). Increased input to the sediments of decomposing organic matter contributes to lower sediment redox potentials and higher concentrations of reducing substances, some of which (e.g. sulfide) may be directly toxic to nymphs (Rasmussen 1988). As oligotrophic lakes become increasingly eutrophic, *Hexagenia* mayflies disappear and are replaced by chironomids, which are more tolerant of low DO.

Nymphs consume organic detritus, algae, bacteria, protozoans, other small organisms, and large amounts of indigestible inorganic matter. They apparently selectively ingest organic matter of high caloric content (Zimmerman, Wissing, and Rutter 1975). Growth rate is a function of temperature; life cycles are completed in as little as 12 weeks under laboratory conditions (Fremling 1967), but require as long as 2 years in northern lakes (Hunt 1953). The life cycle is completed in 1 year or less in the MR below the Twin Cities. In prime habitats, last instar nymphs have been found in concentrations of 340/m^2 (Fremling 1960), and nymphs of various instars at concentrations of 823/m^2 (Carlander et al. 1967). *Hexagenia* nymphs are important members of the aquatic ecosystems, tilling sediments and converting organic detritus into fish food. They are among the largest benthic animals, and their long life cycles ensure their availability to fish at all seasons. Because nymphs pass through many molts, they are food for a wide variety of fish species ((Rasmussen 1988). Vigorous *Hexagenia* populations increase turbidity, and their detritivory may prolong the life of lakes and impoundments by reducing the organic content of sediments.

Two species of *Hexagenia* dominate the UMR watershed. *Hexagenia bilineata* inhabits large rivers, the adults seldom straying far from their banks. *Hexagenia limbata* inhabits lakes and streams as well as large rivers; its adults are often found several miles from their nymphal habitat. The two species tend to emerge en masse from the UMR at intervals of 6 to 11 days, causing nuisance problems from mid-June until mid-August. Lakes within the UMR watershed may also be host to *Ephemera simulans*, a closely related burrowing species (Fremling and Kloek 1969).

Water quality relationships downstream
from metropolitan Minneapolis and St. Paul

Hexagenia mayfly distribution patterns have dramatically documented water quality changes in Pool 2 (river mile (RM) 815.3-847.7), which lies just downstream from the metropolitan Twin Cities (METRO), and in Lake Pepin (RM 764-787) (Fremling and Claflin 1984). Scarpino (1985) reviewed the 1890-1950 water quality history of the UMR in the METRO corridor, where early pollution control was dictated largely by development of the river for navigation. Channelization practices begun in 1878 included dredging and construction of groins that constricted the river, increasing its velocity and ability to transport sewage away from METRO. In 1917, the US Army Corps of Engineers completed the Twin Cities Lock and Dam (now L&D 1), creating a 5-mile pool that received most METRO sewage. In 1930, the Corps finished L&D 2 at Hastings; its 32-mile pool extended upstream to the foot of the Twin Cities L&D and became a resting place for the remainder of METRO sewage, including wastes from packing houses and stockyards. During late summer, the river for 45 miles below St. Paul lacked sufficient oxygen to sustain fish life of any type. Because of intolerable health and aesthetic problems created by the pooled sewage, sewage treatment facilities were constructed in the METRO area (Minneapolis-St. Paul Sanitary District 1961). In succeeding years, most small treatment plants were consolidated with the Metropolitan Waste Control Commission (MWCC) plant at Pig's Eye (RM 836.3); treatment efficiency was increased, effluent quality was markedly improved, by-passes due to combined sewer overflow were reduced, and water quality improved. For example, annual average effluent biological oxygen demand dropped from almost 190 mg/ℓ in 1967 to less than 20 mg/ℓ in 1986 (Fremling and Claflin 1984).

Poor water quality downstream from METRO prior to 1980 was documented by *Hexagenia* distribution. During my studies of 1957-1969 and 1976, 1,164 collections of *H. bilineata* and 209 collections of *H. limbata* were made along the UMR between Cairo, IL, and Brainerd, MN. Only six *H. bilineata* and two *H. limbata* emergences were reported from Pools 1 and 2, even though the broad, silted expanses of Pool 2 were potentially excellent habitat. Both species were abundant in pooled reaches upstream from METRO. Benthos collections made during 1957-1976 substantiated the lack of *Hexagenia* and the domination of Pool 2 by chironomids and tubificid worms, both pollution-tolerant forms (Fremling and Johnson 1989).

Water quality improved markedly in Pool 2 during the 1980s, and mayfly response was dramatic. Benthos sampling by MWCC personnel in July 1985 yielded a wide variety of taxa, including *Hexagenia* of various instars at concentrations of 421/m^2 just above L&D 2. In 1986, one *H. limbata* and 21 *H. bilineata* mass emergences were reported from Pool 2; the insects caused nuisance problems at harbors and in downtown St. Paul (Lewis 1986). On June 23, 1987, mayflies blocked the Highway 494 bridge in south St. Paul, causing two accidents and forcing the Highway Patrol to close it until it could be plowed and sanded (Foley 1987).

Lake Pepin serves as a repository for some of METRO's pollutants; only eight *H. bilineata* and three *H. limbata* collections were made there during 1957-1976. Low numbers of *Hexagenia* nymphs (frequency of occurrence 1.5 percent) and domination of Lake Pepin by *Chironomus* midge larvae (frequency of occurrence 88 percent) were documented (Trapp 1979). Adult midges caused most of the nuisance problems during that period.

Conditions also improved in Lake Pepin after 1980. In 1986, 26 collections of *H. bilineata* and two of *H. limbata* were made during July. Benthos sampling of Lake Pepin in 1986 repeated the study done in 1976; frequency of occurrence of *Hexagenia* nymphs within samples was 84 percent, while that of *Chironomus* larvae was 78 percent. Highest concentrations of *Hexagenia* were in the upper third of the lake (T. Claflin, University of Wisconsin-LaCrosse, personal communication). These data demonstrated that improved water quality allowed *Hexagenia* to thrive in areas that were previously denuded.

Hexagenia crash during the 1988 drought

During the drought of 1988, only two collections of *H. bilineata* were made from Pool 2, and only one collection was made from Lake Pepin. No nuisance problems were reported from either area. In River Lake of Pool 2 (RM 826.2-827.3), *Hexagenia* nymphs numbered about $100/m^2$ in 1987, but none were found in 1988 (D. Hornbach, Macalaster College, personal communication). In weekly DO samples taken by the MWCC at eight sites between METRO and L&D 3 between May 1 and September 30, 1988, 86 percent of values were about 5 mg/ℓ, while 14 percent were 2.9 to 5.0 mg/ℓ. At automatic sampling sites at Pig's Eye (RM 837), Newport (RM 831), Grey Cloud Island (RM 827), and L&D 2 (RM 815) during May 1-September 30, monthly mean DO equaled or exceeded 5 mg/ℓ. However, in neither survey was sampling done at the mud-water interface where DO is usually lowest. Conventional techniques fail to sample this thin stratum upon which *Hexagenia* mayflies and most other benthic invertebrates depend for their respiratory water (Fremling 1963). Because of its low DO and its proximity to sediments that may be laden with heavy metals (Weiner et al. 1984), chlorinated hydrocarbons, and other pollutants, the water at the mud-water interface may be lethal when conventional monitoring techniques indicate that conditions are tolerable.

Because of its large size and shallowness, Lake Pepin is windswept and usually does not thermally stratify. Therefore, its broad expanses of organically rich sediments are potentially excellent *Hexagenia* habitat. However, Lake Pepin has a history of poor summer DO and algal problems in low-flow years such as 1988. At L&D 4, the first dam below Lake Pepin, minimum flows of 5,700 cfs occurred during June 29-30 and July 3-7, 1988. (Average normal summer flow there is about 18,000 cfs; average normal minimum flow is about 12,000 cfs.)

Low river flows during spring and summer of 1988 increased the average hydraulic residence time of Lake Pepin from about 9 days to several weeks, causing increased eutrophic conditions. Anoxic conditions caused by decaying algae were cited as the most likely cause for a July 12-15 fish kill at Maiden Rock, WI (J. Sullivan, Wisconsin Department of Natural Resources, August 22, 1988). At a continuous monitoring site 75 yd off the Minnesota shore near Lake City (RM 771.4), in 4 ft of water (sensor middepth), there were 15 episodes of 1- to 82-hr duration when DO concentrations fell below 5 mg/ℓ during

July 15-September 2. Low DO conditions occurred mainly with a southwest wind, indicating that surface water was pushed toward the Wisconsin shore, causing an undercurrent of low-DO bottom water in the opposite direction (G. Rott, Minnesota Pollution Control Agency, February 7, 1989).

A similar phenomenon was documented on June 23 at RM 771.4 when transect sampling across the lake showed that a southeast wind caused a countercurrent of low DO (0.8 to 2.0 mg/ℓ) water to cover a large area on the Wisconsin half of the lake at depths of 21 to 28 ft (Minnesota Department of Natural Resources, Lake Survey Report). The most extensive temperature and DO measurements from Lake Pepin were made by Renny Foster and his father, Jerry, as part of a science fair project. Using a Yellow Springs Instrument Company DO-temperature meter, they sampled 36 locations throughout Lake Pepin during the last week in August at surface, middepth, and just above the bottom. They noted no thermal stratification, but found a distinct pool of water containing less than 1.0 mg/ℓ DO at depths greater than 26 ft between RM 766 and 770, near the outlet of the lake. Mississippi River backwaters also were impacted by low flow. Goose Lake (RM 788-789) was thermally stratified on June 25 and had less than 0.2 mg/ℓ DO at all depths greater than 6 ft (Minnesota Department of Natural Resources).

These data suggest that *Hexagenia* populations may also have been adversely impacted in other backwaters of the UMR in 1988 when low-flow conditions necessitated reduced flow through navigation dams to maintain pool levels as required by the 9-ft channel project. This probably caused hypoxia at the mud-water interface in large areas. The largest *H. bilineata* emergence of the season normally occurs during the period July 9 to July 12. I have observed it annually in Pool 5A for 31 years. No mass emergence was observed in Pool 5A during that interval in 1989.

Summary

The results of these studies support the use of *Hexagenia* mayfly distribution as a simple, inexpensive method of assessing water quality in the UMR. The replacement of *Hexagenia* by chironomid midges is an ominous sign whether it occurs in a river or a lake. By their presence or absence, *Hexagenia* mayflies monitor DO and many other parameters, including synergistic effects that cannot be measured in other ways. The 1988 crash of *Hexagenia* populations in Pool 2 and Lake Pepin demonstrated that potentially rich *Hexagenia* habitat became intolerable during low-flow conditions, even though conventional water chemistry sampling indicated that water quality was satisfactory or marginal. *Hexagenia* baseline data collected during the past 34 years will be invaluable in judging the effectiveness of future pollution abatement measures. Burrowing mayflies still have not returned to Lake Erie, and only relatively small numbers occur in Green Bay of Lake Michigan. When *Hexagenia* returns in force to these areas, we will know that pollution control efforts there are succeeding.

References

Beeton, A. M. 1961. "Environmental Changes in Lake Erie," Trans. Amer. Fish. Soc. 90(2):153-159.

Bills, T. D., Marking, L. L., and Rach, J. J. 1985. "Toxicity of the Lampricides 3-Trifluoromethyl-4-Nitrophenol (TFM) and 2,5-Dichloro-4-Nitrosalicylanilide (Bayer 73) to Eggs and Nymphs of the Mayfly (*Hexagenia*) sp.," Great Lakes Fish. Comm. Tech. Rept. No. 47, pp 13-23.

Britt, N. W. 1955. "*Hexagenia* (Ephemeroptera) Population Recovery in Western Lake Erie Following the 1953 Catastrophe," Ecol. 36(3):520-522.

Carlander, K. D., Carlson, C. A., Gooch, V., and Wenke, T. L. 1967. "Populations of *Hexagenia* Mayfly Naiads in Pool 19, Mississippi River, 1959-1963," Ecol. 48:873-878.

Carr, J. F., and Hiltunen, J. K. 1965. "Changes in the Bottom Fauna of Western Lake Erie from 1930 to 1961," Limnol. Oceanog. 10(4):551-569.

Clements, J. R., and Kawatski, J. A. 1984. "Occurrence of Polychlorinated Biphenyls (PCBs) in Adult Mayflies (*Hexagenia bilineata*) of the Upper Mississippi River," Jour. Freshwater Ecol. 2:611-614.

Edmunds, G. F., Jr., Jensen, S. L., and Berner, L. 1976. The Mayflies of North and Central America. Univ. Minnesota Press, Minneapolis, MN.

Encyclopaedia Britannica Educational Corporation. 1973. "The Mayfly: Ecology of an Aquatic Insect," 16 mm film (sound, 15 min).

Flattum, R. 1963. "Apparent Effects of Refrigeration on the Rate of Embryonic Development of Mayfly (*Hexagenia limbata*) Eggs," Jour. Minn. Acad. Sci. 31(1):82-83.

Foley, E. 1987 (25 Jun). Some Shiver, Others Rejoice at Mayfly Blizzard," Minneapolis Star and Tribune, pp 1A, 10A.

Fremling, C. R. 1960. "Biology of a Large Mayfly, *Hexagenia bilineata* (Say), of the Upper Mississippi River," Iowa St. Univ. Agr. Home Econ. Exp. Sta. Res. Bull. 482:842-852.

__________. 1963. "A Method for Determining the Dissolved-Oxygen Concentration Near the Mud-Water Interface," Limnol. Oceanogr. 8(3):363-364.

__________. 1964. "Mayfly Distribution Indicates Water Quality on the Upper Mississippi River," Science 146(3648):1164-1166.

__________. 1964. "Mayfly Distribution Indicates Water Quality on the Upper Mississippi River," Science 146(3648):1164-1166.

__________. 1967. "Methods for Mass-Rearing *Hexagenia* Mayflies (Ephemeroptera: Ephemeridae)," Trans. Amer. Fish. Soc. 96(4):407-410.

Fremling, C. R. 1968. "Documentation of a Mass Emergence of *Hexagenia* Mayflies from the Upper Mississippi River," Trans. Amer. Fish. Soc. 97:278-280.

__________. 1970. "Mayfly Distribution as a Water Quality Index," Water Poll. Control Res. Ser. 16030 DQH, US Environmental Protection Agency.

__________. 1973. "Factors Influencing the Distribution of Burrowing Mayflies Along the Mississippi River," Proc., 1st Internat. Conf. Ephemeroptera, W. L. Peters and J. G. Peters, eds., E. J. Brill Publ., Leiden, The Netherlands, pp 12-25.

__________. 1975. "Acute Toxicity of the Lampricide 3-Trifluoromethyl-4-Nitrophenyl (TFM) to Nymphs of Mayflies (*Hexagenia* sp.)," Invest. Fish Control 58.

__________, and Claflin, T. O. 1984. "Ecological History of the Upper Mississippi River," Contaminants in the Upper Mississippi River. J. G. Weiner, R. V. Anderson, and D. R. McConville, eds., Proc., 15th Ann. Meeting Miss. River Res. Consort., Butterworth Publ., Boston, MA.

__________, and Johnson, D. K. 1989. "Recurrence of *Hexagenia* Mayflies Demonstrates Improved Water Quality in Pool 2 and Lake Pepin, Upper Mississippi River," Proc., 5th Internat. Conf. Ephemeroptera (in press).

__________, and Kloek, C. P. 1969. "Distribution and Emergence Patterns of Mayflies, *Ephemera simulans* (Ephemeroptera: Ephemeridae)," Jour. Minn. Acad. Sci. 35(2,3):102-103.

__________, and Mauck, W. L. 1980. "Methods for Using Nymphs of Burrowing Mayflies (Ephemeroptera, *Hexagenia*) as Toxicity Test Organisms," Aquatic Invertebrate Bioassays, A. L. Buikema, Jr., and J. Cairns, Jr., eds., STP 715, American Society for Testing and Materials, Philadelphia, PA, pp 81-97.

__________, and Schoening, G. L. 1973. "Artificial Substrates for *Hexagenia* Mayfly Nymphs," Proc., 1st Internat. Conf. Ephemeroptera, W. L. Peters and J. G. Peters, eds., E. J. Brill Publ., Leiden, The Netherlands, pp 209-211.

Henry, M. G., Chester, D. N., and Mauck, W. L. 1986. "Role of Artificial Burrows in *Hexagenia* Toxicity Tests; Recommendations for Protocol Development," Environ. Toxicol. Chem. 5:553-559.

Hilsenhoff, W. L. 1987. "An Improved Biotic Index of Organic Stream Pollution," Great Lakes Entomol. 20:31-39.

Hunt, B. P. 1953. "The Life History and Economic Importance of a Burrowing Mayfly, *Hexagenia limbata*, in Southern Michigan Lakes," Mich. Cons. Dept. Bull. Inst. Fish. Res 4:1-151.

Lee, J. 1962 (25 Feb). "Sign of Sick River: Green Bay Flies Are Gone," Green Bay Press-Gazette, p M-6.

Lewis, D. 1986 (3 Jul). "Mayflies Stage July Invasion," St. Paul Pioneer Press and Dispatch.

Mauck, W. L., and Olson, L. E. 1977. "Polychlorinated Biphenyls in Adult Mayflies (*Hexagenia bilineata*) from the Upper Mississippi River," Bull. Environ. Contam. Toxicol. 17:387-390.

Mills, H. B., Starrett, W. C., and Bellrose, F. C. 1966. "Man's Effect on the Fish and Wildlife of the Illinois River," Ill. Nat. Hist. Surv. Biol. Notes 57.

Minneapolis-St. Paul Sanitary District. 1961. "Pollution and Recovery Characteristics of the Mississippi River for the Period 1926-1955," Vol 1, No. 3.

Needham, J. G., Traver, J. R., and Hsu, Yin-Chi. 1935. The Biology of Mayflies, Comstock Publ., Ithaca, NY.

Peters, W. L. 1988. "Origins of the North American Ephemeroptera Fauna, Especially the Leptophlebiidae," Mem. Ent. Soc. Can. 144:13-24.

Rasmussen, J. B. 1988. "Habitat Requirements of Burrowing Mayflies (Ephemeridae: *Hexagenia*) in Lakes, with Special Reference to the Effects of Eutrophication," J. N. Am. Benthol. Soc. 7(1):51-64.

Scarpino, P. V. 1985. Great River: An Environmental History of the Upper Mississippi, 1890-1950, Univ. Missouri Press, Columbia, MO.

Swanson, G. A. 1967. "Factors Influencing the Distribution and Abundance of *Hexagenia* Nymphs (Ephemeroptera) in a Missouri River Reservoir," Ecol. 48:216-255.

Trapp, K. E. 1979. "A Survey of the Benthic Community of Lake Pepin and a Study of the Influence of Various Physical Factors on the Distribution of Selected Taxa," M. S. thesis, Univ. Wisconsin, LaCrosse, WI.

Weiner, J. G., Jackson, G. A., May, T. W., and Cole, B. P. 1984. "Longitudinal Distribution of Trace Elements (As, Cd, Cr, Hg, Pb, and Se) in Fishes and Sediments in the Upper Mississippi River," Contaminants in the Upper Mississippi River, J. G. Weiner, R. V. Anderson, and D. R. McConville, eds. Proc., 15th Ann. Meeting Miss. River Res. Consort., Butterworth Publ., Boston, MA.

Zimmerman, M. C., Wissing, T. E., and Rutter, R. P. 1975. "Bioenergetics of the Burrowing Mayfly, *Hexagenia limbata*, in a Pond Ecosystem," Verh. Internat. Verein. Limnol. 19:3039-3049.

SUMMARY OF THE WORKSHOP

On 8-10 August 1989 a workshop on techniques for evaluating aquatic habitats was held at the US Army Engineer Waterways Experiment Station (WES). The workshop was attended by planners and biologists from various Corps of Engineers District and Division offices.

Goals of the Workshop

The workshop was held to discuss techniques for evaluating aquatic habitats in rivers, streams, and reservoirs, with special emphasis on large river systems. As the Corps of Engineers continues its role in maintaining the Nation's waterways for commercial traffic, continued technology transfer between District and Division planners and biologists and the research and development community is imperative. Environmental impact assessment has rapidly become an integral part of the Corps mission and will continue to play a vital role in all Corps projects.

The primary goal of the workshop was to make the attendees aware of techniques that are effective in evaluating aquatic habitats. Discussions during the workshop dealt primarily with aquatic habitat evaluation utilizing fish, invertebrates, and water quality, and focused on the sampling methods used to gain information on these biological and physical aspects of aquatic environments. In addition, statistical design, habitat modeling, habitat mapping, and laboratory techniques were discussed.

Synopsis of Topics Discussed

The workshop was divided into four sessions which addressed major topics dealing with defining and evaluating aquatic habitats.

The first session dealt primarily with the physical and biological characteristics of aquatic habitats and addressed aquatic habitat classification. The focus of this session was to make workshop participants aware of basic physical and biological processes that drive ecological processes in aquatic systems, and to illustrate the need to differentiate various aquatic habitat types.

The second session was designed to present techniques that are available for evaluating aquatic habitats. Once the physical and biological processes of a system are understood and habitats are defined, appropriate evaluative techniques are necessary to assess the ecological value of the aquatic habitat types within that system. Major topics during this session dealt with techniques used to sample fish (larvae and adult) and invertebrates. In addition, time was devoted to water quality problems in reservoirs.

Information on data analysis and interpretation was presented in the third session. The primary topics discussed were habitat classification and application of geographic information systems and laboratory experiments to evaluate environmental impacts.

The last session dealt with actual case studies in aquatic systems. Major topics discussed in this session were the benefits of long-term field studies to assess possible impacts on fisheries communities in aquatic systems and the use of certain species of invertebrates to monitor water quality in reservoirs and rivers.

Major Findings of the Workshop

Major points of the workshop, based on the presentations, comments, and discussions, are as follows:

- a. Some attendees expressed concern with the use of models, such as the Habitat Evaluation Procedures (HEP) and Instream Flow Incremental Methodology (IFIM), in dealing with water resource-related problems. It was suggested that qualitative and quantitative data from site-specific studies should also be considered for predicting the impacts of Corps activities.
- b. There is a need to standardize the definitions of various habitats in river systems. These definitions often differ between engineers and ecologists.
- c. Short-term monitoring of biological systems may be inadequate to answer questions associated with impact assessment. Long-term monitoring would allow a better understanding of the influences of man-made and natural disturbance on ecosystem processes.
- d. Construction of certain types of habitat in areas that have been negatively impacted by Corps activities is an important means of mitigation.
- e. Certain species of fish and invertebrates can be used to monitor degradation or enhancement of aquatic habitats.
- f. Laboratory experiments with select organisms can be used to predict impacts in aquatic systems.